JURNAL TEKNIK SIPIL CENDEKIA
e-ISSN : 2723-3375
doi : **10.51988/jtsc.v7i3.605**
pp : 622-631

Analysis of Slope Stability Against River Openings Due to the Influence of Sedimentation at the Tinggar Buntut Water Gate

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Received : 18 Juni 2026 Revised : 30 Juli 2026 Accepted : 31 Juli 2026

Abstract
Sedimentation in river channels may increase lateral earth pressure and reduce slope stability around hydraulic structures. However, studies concerning the effect of sediment accumulation on sheet pile-supported slopes at irrigation structures remain limited. This study evaluates the influence of sedimentation on slope stability at the Tinggar Buntut Water Gate, Kali Sadar River, using the Rankine method and the finite element method. Soil parameters were obtained from BBWS Brantas, while the sediment thickness of 1.5 m was estimated and validated by comparing riverbed elevations derived from Google Earth Pro historical imagery between 2019 and 2025. Soil behavior was simulated using the Mohr–Coulomb model under existing and sedimented conditions. The results show that active earth pressure increased from 74.93 kN/m to 126.62 kN/m, while the safety factor decreased from 1.44 to 0.85. Numerical analysis also indicated that the safety factor decreased from 1.7342 to 1.4420, accompanied by an increase in deformation from 3.40 × 10^{-3} m to 9.06 × 10^{-3} m.

Keywords: *river sedimentation, slope stability, lateral earth pressure, Rankine method, Plaxis 2D.*

INTRODUCTION

In the hydrological cycle, where the river has a function as an important part of water distribution, water supply for irrigation needs, and supports the flood control system. However, with the increase in human activities accompanied by changes in land use, it has triggered various environmental problems in watersheds, especially sedimentation. The sedimentation process can occur when eroded materials such as soil particles and other materials are carried by the water flow and then deposited at the location with a lower flow speed. If the sedimentation continues continuously, the elevation of the river bed will increase, the width of the channel will gradually narrow, and the capacity of the river to drain water will be decreasing. This condition can ultimately reduce effectiveness as well as a source of disruption to the sustainability of water resource infrastructure [1].

In the Mojokerto Regency area, precisely around the Tinggar Buntut Water Gate, the Kali Sadar River is one of the locations that experiences sediment accumulation. The existence of hydraulic buildings in this area has a very important role in regulating flow, flood control, and distributing irrigation water to surrounding agricultural land. As an effort to be able to maintain the stability of the river bank where a retaining wall in the form of concrete sheet piles has been built on both sides of the stream. However, conditions in the field have indicated that sediment deposits are still forming in the downstream part of the river. This accumulation not only increases the elevation of the river bed but also changes the cross-section of the stream. This situation is a marker of the ongoing sedimentation process and can have an impact on the condition of the surrounding soil which ultimately has the potential to affect the performance of the river structure[2].

Sedimentation not only affects the hydraulic condition of the river but can also reduce the stability of the slope and the performance of the soil retaining structure. As sediment deposits continue to increase where the soil mass around the sheet pile increases. This condition is the cause of greater lateral soil pressure received by the structure. This increase in pressure can reduce the value of the slope safety factor so that the potential for instability will be higher. If not handled, the retaining structure is at risk of greater deformation and has the potential to fail [3]. Therefore, the influence of sedimentation needs to be analyzed as an important part of maintaining the performance of hydraulic buildings for the long term as well as ensuring the safety of the river infrastructure structure is well maintained. A number of previous studies have indicated slope and sheet pile stability using analytical calculations based on Rankine theory or numerical simulations using the finite element method. However, most of these studies only focus on the initial condition of the soil without considering changes due to sediment deposits that continue to increase over time. As a result, information about the influence of sediment accumulation on the magnitude of lateral soil pressure and slope stability around hydraulic buildings is still very limited, more specifically on the Kali Sadar River in the Tinggar Buntut Water Gate area [4].

This study was conducted as an effort to understand the impact of sedimentation on the engineering conditions in the Tinggar Buntut Water Gate, especially related to lateral soil pressure and slope stability strengthened by sheet piles. The analysis was carried out by comparing two conditions, namely the existing state and the state after sedimentation by using the Rankine theory approach and the 2D Plaxis numerical simulation. From these two approaches, changes in lateral soil pressure, slope deformation, and safety factors are then evaluated to be able to see the effect of sediment accumulation. The results obtained are expected to be a basis for consideration in the preparation of maintenance strategies and support for river infrastructure management in a more sustainable manner.

Research Questions

The formulation of the problems in this study is prepared based on various problems that have been described in the background so that the research has a clear direction:

1. How does sediment accumulation affect active lateral earth pressure acting on sheet piles and the stability of adjacent slopes at the Tinggar Buntut Water Gate?
2. How do existing and sedimented conditions influence active and passive earth pressures around the sheet pile structure of the Kali Sadar River based on Rankine theory?
3. How do sedimented conditions affect slope deformation and the Safety Factor (SF) of sheet pile-supported slopes according to Plaxis 2D numerical simulations?

Soil

Soil in geotechnical engineering is considered a three-phase material consisting of solid particles, water, and air. The behavior of soil in engineering structures is strongly influenced by its physical and mechanical properties, which affect slope stability, lateral earth pressure distribution, bearing capacity, and the deformation characteristics of retaining structures[5]. Several parameters are commonly used to describe soil behavior, including unit weight (γ), cohesion (c), internal friction angle (φ), moisture content, and permeability.

In addition to its physical and mechanical properties, soil behavior is highly dependent on pore-water conditions. Variations in pore-water pressure influence the effective stress, which governs the shear strength of the soil mass. An increase in pore-water pressure reduces the effective stress and consequently decreases the soil's resistance to shear forces, resulting in a higher potential for slope instability[6]. Therefore, understanding soil characteristics and their response to environmental changes is essential for estimating lateral earth pressure and evaluating slope stability in geotechnical structures.

For riverbank slopes, soil properties play an important role in determining the response of the slope and retaining system to changes in geometry and external loading. Variations in soil unit weight, cohesion, and internal friction angle affect the magnitude of lateral earth pressure and the resistance of the soil mass against deformation. Previous studies have shown that finite-element methods and strength-reduction techniques can effectively evaluate the stability of sheet pile-supported slopes and estimate the corresponding factor of safety[7]. At the Tinggar Buntut Water Gate, sediment accumulation and changes in riverbed geometry are expected to modify the stress distribution in the surrounding soil mass and increase the lateral pressure acting on the sheet pile structure. Therefore, soil parameters were incorporated into the Rankine earth pressure analysis and the Mohr–Coulomb constitutive model in Plaxis 2D to evaluate the stability response of the sheet pile-supported slope under existing and sedimented conditions.

River Sedimentation

The sediment deposition process can occur when the water stream no longer has enough hydraulic energy to transport the erosioned particles so that the material begins to settle at the bottom of the stream. These particles had previously been carried by moving water from various sources of erosion then stopped and accumulated as their speed decreased. The deposits that are formed can be in the form of sand, silt, clay, gravel, and organic materials that come from natural processes such as weathering and erosion or human activities in the watershed [8].

According to [3], Sediment deposition is commonly associated with changes in hydraulic conditions, such as lower flow velocities, fluctuations in water depth, channel widening, and the presence of hydraulic structures that influence sediment transport processes. Prolonged sediment accumulation may result in riverbed aggradation, channel constriction, and modifications to channel geometry. In geotechnical engineering, these changes can increase lateral loading on retaining systems and contribute to a reduction in the stability of adjacent slopes and riverbank structures.

At the Tinggar Buntut Water Gate, sediment accumulation is particularly relevant because changes in the riverbed profile may alter the loading conditions around the sheet pile-supported slope. The sedimentation in this study was modeled as an approximately 1.5 m thick sediment layer based on the interpretation of Historical Imagery and Elevation Profile data for the period 2019–2025. The changes in lateral earth pressure, slope deformation and Factor of Safety due to sediment deposition were evaluated by comparing the sedimented state with the existing condition.

Rankine Earth Pressure Theory

Rankine theory is used to analyze the lateral earth pressure acting on retaining structures based on the plastic equilibrium condition of soil. In this theory, earth pressure is classified into active earth pressure and passive earth pressure, which are used to evaluate the stability of retaining structures and slopes [9].

Active Earth Pressure According to Rankine

Active earth pressure occurs when a retaining structure moves away from the soil mass, causing the horizontal stress within the soil to decrease until it reaches the active failure condition. Under this condition, the soil exerts a pushing force on the retaining structure and produces the minimum lateral earth pressure [9]. The active earth pressure coefficient according to Rankine theory is calculated using Equation

$$K_a = \tan^2(45° - \frac{\varphi}{2}) \quad (1)$$

Where:

K_a = Active earth pressure coefficient

φ = Internal friction angle of soil (°)

The magnitude of active earth pressure stress is calculated using Equation

$$\sigma_a = Ka.\gamma.H \quad (2)$$

Where:

σ_a = Active earth pressure stress (kN/m²)

γ = Unit weight of soil (kN/m³)

H = Height of soil (m)

The total active earth pressure force is calculated using Equation

$$Pa = \frac{1}{2}.ka.\gamma.H^2 \quad (3)$$

Where:
Pa = Total active earth pressure force (kN/m)

Passive Earth Pressure According to Rankine Theory
Passive earth pressure occurs when a retaining structure moves toward the soil mass, causing the horizontal stress within the soil to increase until it reaches the passive failure condition. Under this condition, the soil provides maximum resistance against the movement of the retaining structure [9] .
The passive earth pressure coefficient according to Rankine theory is calculated using Equation

$Kp = \tan^2 (45° + \frac{\varphi}{2})$ ....(4)

Where:
Kp = Passive earth pressure coefficient
φ = Internal friction angle of soil (°)
The magnitude of passive earth pressure stress is calculated using Equation

$\sigma_p = Kp. \gamma. H$ ....(5)

Where:
σ_p = Passive earth pressure stress(kN/m²)
γ = Unit weight of soil (KN/m^3)
H = Height of soil (m)
The total passive earth pressure force is calculated using Equation

$Pp = \frac{1}{2}. kp . \gamma. H^2$ ....(6)

Where:
Pp = Total passive earth pressure forceZ(KN/m)

Plaxis 2D 8.6
Plaxis 2D software version 8.6 is a program based on the finite element method (FEM) which is used for the purpose of analyzing deformation behavior and soil stability. Modeling of geotechnical conditions can be done with a plane strain or axisymmetric approach. In addition, this device is also equipped with a gratific feature that will allow users to build model geometry, enter soil parameters, determine loading conditions, and systematically form mesh [10].

The behavior of the soil in this study was modeled using the Mohr–Coulomb approach to provide an overview of the elastic–plastic properties of the soil. The model is determined by a number of parameters including content weight (γ), Young modulus (E), Poisson ratio (μ), cohesion (c), deep shear angle (φ), and dilation angle (ψ). The determination of slope safety factors is carried out through the phi/c reduction method. From the analysis process, which can be obtained with outputs in the form of total displacement, voltage distribution, collapse field, and safety factor values compared to existing conditions and sedimentation conditions [11].

METHOD

Study Area
The study was conducted on the Kali Sadar River, located in Tinggar Buntut Village, Bangsal District, Mojokerto Regency, Indonesia. The study area is situated between coordinates 667067.00 m E and 9173635.00 m S and 667222.00 mE and 9173507.00 mS in the UTM Zone 49S coordinate system. The proximity of the research location to the Tinggar Buntut Water Gate is the main reason for its selection because this structure plays an important role in river regulation, flood control, and irrigation supply for agricultural areas in Bangsal District and its surroundings.

Field observations and historical imagery indicate sediment accumulation around the study area, which may alter riverbed geometry and increase the lateral earth pressure acting on the sheet pile structure. Consequently, sediment deposition may reduce slope stability and affect the long-term performance of the hydraulic structure.

Figure 1. Study Area

Research Procedure
The initial stage of the research was carried out by reviewing various literature related to river sedimentation, lateral soil pressure, slope stability, Rankine theory, and modeling using Plaxis 2D. After that, the collection of primary

or secondary data is carried out as the basis of analysis. The data obtained was then processed to be used in lateral soil pressure calculations with the Rankine approach and numerical simulations using Plaxis 2D version 8.6. The results of the two methods were then analyzed and compared to see the effect of sedimentation on lateral soil pressure changes and slope stability in conditions before and after sedimentation occurred.

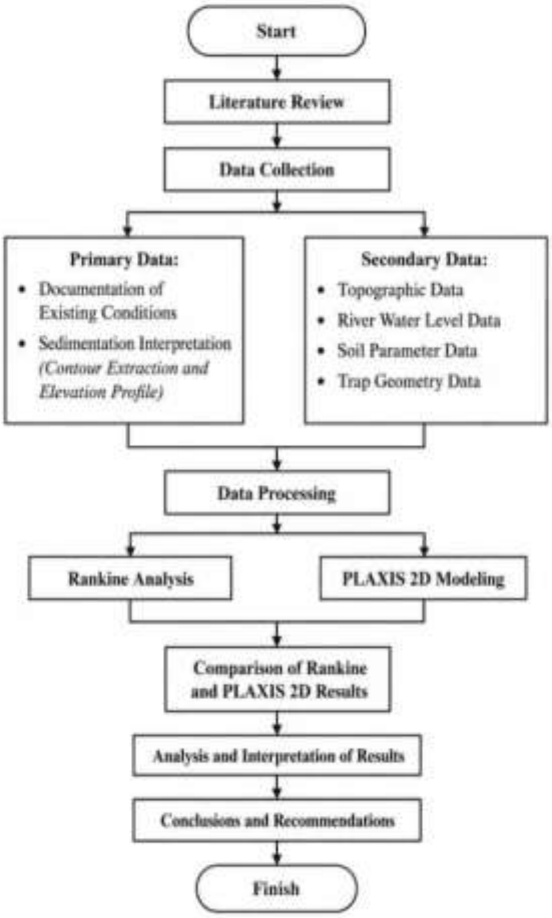

Figure 2. Research Flowchart

Research Data

In this study, lateral soil pressure analysis using the Rankine method and slope stability modeling using Plaxis 2D version 8.6 was carried out by using primary data and secondary data as input parameters. All data needed in this study are then grouped into several categories as follows:

1. Topographic Data

Topographic data were used to define the slope geometry, riverbed elevation, and cross-sectional profile of the Kali Sadar River for the numerical modeling and stability analysis.

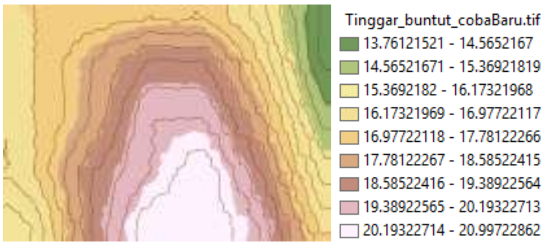

Figure 3. Topographic Contour Map

2. Soil Parameters

The soil parameters used in this study included unit weight (γ), cohesion (c), internal friction angle (φ), elastic modulus (E), Poisson's ratio (ν), and dilatancy angle (ψ). These parameters were used as input data for the Rankine earth pressure analysis and the Mohr–Coulomb soil model in Plaxis 2D.

Tabel 1. Soil Parameters

Parameter	Tanah Timbunan	Tanah Asli	Tanah Dasar Keras	Turap Beton
Model Material	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Elastic Plate
Jenis Drainase	Drained	Drained	Drained	-
γ_{unsat} (kN/m³)	18	18	19	-
γ_{sat} (kN/m³)	19	19	20	-
Eref (kN/m²)	20	20	30	-
ν	0,30	0,30	0,30	0,30
c (kN/m²)	20	20	20	-
φ (°)	30	30	35	-
ψ (°)	0	0	0	-
EA (kN/m)	-	-	-	$2{,}10 \times 10^8$
EI (kNm²/m)	-	-	-	2.1
Berat Sendiri (kN/m/m)	-	-	-	25

3. River Water Level Data

In the analysis model used where groundwater conditions and pore water pressure that affect slope stability are determined on the basis of available river water level data.

4. Sedimentation Data

Determination of sedimentation conditions in the basic analysis in the estimated sediment thickness of around ±1.5 m. This value can be obtained from the results of Google Earth Pro data interpretation in the form of historical imagery and elevation profiles. Based on observations from the range of 2019 to 2025 where it can be seen that there is an accumulation of sediment which is then used as a reference in modeling sedimentation conditions in this study.

Figure 4. Existing and Sedimented Conditions

5. Sheet Pile Geometry Data

In the analysis process, sheet pile geometry data was used with high coverage of the structure, planting depth, and its location on the slope. The data can first be collected and then entered into the model as a representation of the retaining structure. Furthermore, where these parameters are used as the main reference in modeling as well as to be able to assess the stability of the slope under the conditions under which the analysis is carried out.

RESULTS AND DISCUSSION

Rankine Earth Pressure Analysis

Tabel 2. Results of Rankine Method Analysis

Parameter	Existing Condition	Sedimented Condition
Active earth pressure (kN/m)	74,93	126,62
Passive earth pressure (kN/m)	108	108
Faktor Safety Factor (SF)	1,44	0,85

Based on Table 2, it can be seen that sedimentation conditions have an effect in the form of an increase in active soil pressure from 74.93 kN/m to 126.62 kN/m. This is related to the addition of soil mass due to sediment deposits which then add lateral load to the sheet pile structure. Meanwhile, the passive soil pressure value was recorded unchanged at 108.00 kN/m because in the analysis carried out the depth of sheet pile planting was maintained the same under both conditions.

The decrease in safety factors occurred in line with an increase in active soil pressure due to sedimentation from 1.44 in the existing condition to 0.85 in the sedimentation condition. In the criteria presented by [Author] where the change in value indicates a degradation of slope stability triggered by sediment accumulation [12]. In the initial condition with a value of 1.44, it still indicates a relatively stable slope, while a value of 0.85 already indicates unstable conditions. Therefore, it can be understood that the sedimentation process has a role in terms of increasing lateral soil pressure as well as decreasing the level of slope stability around the Tinggar Buntut Sluice Gate.

Geometry Modeling

Slope stability analysis was conducted using Plaxis 2D Version 8.6 under plane strain assumptions. The numerical model was established using Digital Elevation Model (DEM) data, field observations, and structural information obtained from[13]. Input parameters included slope geometry, soil characteristics, and groundwater conditions. These data were incorporated into the model to accurately represent the existing site conditions and to assess the impact of sediment accumulation on slope stability and the performance of the sheet pile structure.

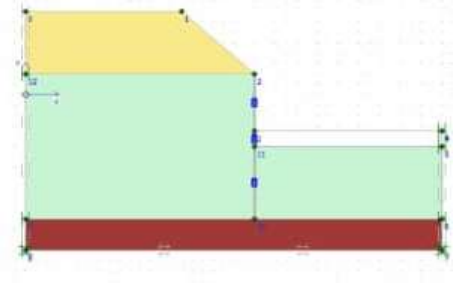

Figure 5. Geometry Model of the Existing Condition

The initial condition of the location before the sediment accumulation occurred is given an overview through the slope geometry as shown in Figure 5. The preparation of this model covers the bottom soil layer, the slope of the river bank, and the sheet pile element which is a form of representation of real conditions in the field. Based on topographic data and the results of field observations where the geometry was formed as a basic model which was then used as a reference to assess changes in slope stability due to sedimentation.

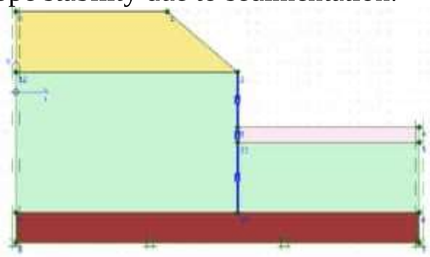

Figure 6. Geometry Model of the Sedimented Condition

Figure 6 presents the slope geometry under sedimented conditions, incorporating an additional sediment layer with a thickness of 1.5 m on the riverbed. The presence of this sediment deposit modified the river cross-sectional profile and potentially increased the loading acting on the slope and sheet pile structure. These modified conditions were subsequently analyzed to assess the influence of sediment accumulation on slope deformation and overall stability.

Total Displacement

A total displacement analysis was carried out using Plaxis 2D to assess the deformation response of the slope due to sediment accumulation. The analysis results were presented as total displacement contours for both existing and sedimented conditions. With these contours, the assessment of deformation can be carried out both in terms of its magnitude or its distribution pattern in space. This condition is then associated with changes in the shape of the slope and additional loads that arise due to the sediment deposition process.

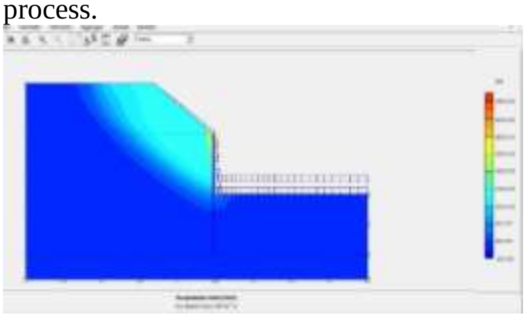

Figure 7. Total Displacement under the Existing Condition

In the existing conditions where Figure 7 can be an indication of the distribution of the total displacement contour on the slope. The greatest displacement can be seen concentrated at the top of the slope adjacent to the sheet pile structure. This condition indicates that the deformation is influenced by the weight of the soil itself and the pressure of the soil working in the slope system. Even so, the relatively small displacement is an indication that the slope stability can still be maintained in these initial conditions.

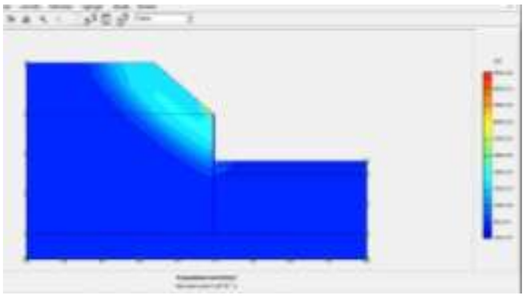

Figure 8. Total Displacement under the Sedimented Condition

In sedimentation conditions where the contours of total displacement shown in Figure 8 are able to show changes quite clearly. Compared to the initial conditions itself, the area that underwent deformation became wider after the formation of sediment deposits as thick as 1.5 m on the riverbed. This can happen because the additional load from the sediment creates an increase in tension on the slope system which then triggers greater soil movement around the sheet pile structure and the surrounding slopes. These findings indicate that sediment buildup can magnify slope deformation and in the long term potentially reduce its stability levels.

Safety Factor
For slope stability assessment, the phi-c reduction approach was used with the implementation through Plaxis 2D software to obtain Safety Factor (SF) values in two conditions, namely existing conditions and conditions after sedimentation. The results of the calculation of the safety factor are then used as a basis to be able to see how sediment accumulation affects the stability of the slope held by the sheet pile structure in the Tinggar Buntut Water Gate area. A comparison between these two SF conditions will allow the magnitude of changes in slope behavior due to sedimentation to be identified and analyzed in a quantitative way.

Table 3. Comparison of Safety Factors Obtained from Rankine and Plaxis 2D Analyses

Analysis Method	Existing Condition SF	Sedimented Condition SF	SF Reduction
Rankine	1,44	0,85	40,97%
Plaxis 2D	1,73	1,44	16,85%

From Table 3, it can be seen that there is a consistent pattern between the results of the Rankine and Plaxis 2D methods with a decrease in the value of the safety factor after the sediment buildup. The calculation with the Rankine method indicates that the safety factor drops from 1.44 to 0.85 which means that it is reduced by around 40.97%. On the other hand, the results of the Plaxis 2D simulation also show a decrease from 1.7342 to 1.4420 with a percentage decrease of 16.85%.

The difference in safety factor values produced by the two methods arises because the basis of the analysis approach is not the same. In the Rankine method where slope stability is determined through a simplified calculation of soil pressure by looking at the balance between active and passive conditions. Meanwhile, Plaxis 2D uses an elemental approach that is able to include various aspects such as the geometric shape of the slope, the mechanical characteristics of the soil, the tension–strain response, soil deformation, and the interaction between the soil and the structure so that the conditions in the field can be described more closely [14].

The results of both analysis methods indicated a similar direction of change even though the value of the security factor obtained was not the same. The decrease in slope stability continues to occur along with the increase in sediment deposits. This condition can be explained because the accumulation of sediment creates an increase in lateral pressure on the sheet pile structure which ultimately makes the slope stability in the area around the Tinggar Buntut Water Gate decrease [15].

CONCLUSION

Based on the results of this study, sediment accumulation in the Kali Sadar River around the Tinggar Buntut Water Gate significantly affects lateral earth pressure and the stability of the slope supported by the sheet pile structure. According to the Rankine analysis, the active earth pressure increased from 74.93 kN/m under existing conditions to 126.62 kN/m after sedimentation. This increase was accompanied by a reduction in the safety factor from 1.44 to 0.85, indicating that sediment accumulation considerably decreases slope stability.

The numerical analysis using Plaxis 2D also showed a similar trend. The safety factor decreased from 1.7342 under existing conditions to 1.4420 after sediment accumulation, representing a reduction of 16.85%. In addition, the total deformation increased from 3.40×10^{-3} m to 9.06×10^{-3} m, indicating that sediment deposits increase the load acting on the slope and sheet pile system, resulting in greater displacement and reduced structural performance.

Based on the commonly accepted safety criterion, where a safety factor greater than 1.25 indicates stable conditions, the Plaxis 2D results show that the slope remains stable under static conditions despite the reduction in stability caused by sedimentation. In contrast, the Rankine method predicts an unstable condition after sediment accumulation, with a safety factor below the minimum requirement. The comparison between the Rankine and Plaxis 2D methods indicates that variations in the safety factor values are influenced by the different analytical approaches used by each method. Rankine theory employs simplified assumptions and idealized conditions, whereas Plaxis 2D utilizes the finite element method to provide a more comprehensive representation of soil behavior, structural response, and soil–structure interaction[16]. Although the approaches are different, both methods consistently demonstrate that sediment accumulation has a negative impact on slope stability at the study location.

This study has several limitations. The soil parameters used in the analysis were obtained from secondary data provided by BBWS Brantas, while the sediment thickness of 1.5 m was estimated from historical imagery and elevation profiles derived from Google Earth Pro. Furthermore, this study did not include detailed hydraulic modeling, field measurements of sediment thickness, or redesign alternatives for the sheet pile structure.

Based on these findings, several technical recommendations can be proposed to maintain the long-term stability of the Tinggar Buntut Water Gate area. Periodic sediment dredging should be carried out to reduce the additional lateral load caused by sediment accumulation. Regular monitoring of sheet pile deformation and annual topographic surveys are also necessary to detect changes in riverbed geometry. In addition, further investigations involving field measurements and comprehensive hydraulic analyses are recommended to improve the accuracy of future studies. Slope stability assessments should also be updated whenever significant sediment deposition occurs to ensure the safety and sustainability of the hydraulic infrastructure.

ACKNOWLEDGMENTS

The author would like to express his sincere thanks and praises to Allah, the Exalted and Glorious, for His kindness, guidance and blessings which helped him to accomplish this research successfully. The author would also like to thank his lovely parents and family for their unending prayers, motivation, moral support and priceless sacrifices for the academic journey and the completion of this study. We also thank the Faculty of Engineering, Universitas Dr. Soetomo for the academic advice and support during the research process, and BBWS Brantas for providing the supporting data related to the study region of Tinggar Buntut Water Gate. The author also thanks all the parties who contributed in the field observations, data collection and compilation, sedimentation assessment, Rankine earth pressure analysis, and numerical modeling using Plaxis 2D, which made the successful completion of this research on the influence of sediment accumulation to lateral earth pressure and stability of the sheet pile-supported slope possible.

REFERENCES

[1] G. J. Arief, “Analisis Laju Erosi dan Sedimentasi Berbasis Arcgis pada DAS,” vol. 05, no. 01, pp. 583–595, 2025.

[2] P. K. L. dan I. H. T. S. dan B. D. P. Nurul Ulil Albab, “Jurnal rekayasa sipil dan lingkungan,” vol. 5, no. September, 2025.

[3] M. S. Dr. Naharuddin, *pengelolaan DAS dan Aplikasinya dalam proses belajar mengajar*. 2020.

[4] B. Suprapto *et al.*, “Model Reduksi Erosi dan Sedimentasi Daerah Aliran Sungai (Das) Brantas Hulu Sebagai Usaha Konservalasi lahan dan sumberdaya air,” vol. 11, no. 3, pp. 125–133, 2022.

[5] 2020. A. K. Salam, Ilmu Tanah. Yogyakarta, Indonesia, *Ilmu Tanah*. 2020.

[6] A. S. L. dan D. P. T. Hakam, *Stabilitas Lereng dan Dinding Penahan Tanah*. 2022.

[7] A. S. Al-banaa, “Study on slope stability of frame prestressed anchor sheet pile wall with finite element strength reduction method,” vol. 7, no. 1, pp. 49–57, 2021.

[8] humairo Saidah, *drainase perkotaan*. 2021.

[9] B. M. Das, *Mekanika tanah 2 2023*. 2023.

[10] A. Malik, Y. Fajarwati, Endaryanta, M. Nuruzzaman, and N. A. Nur, *Plaxis 2D Pada Permasalahan Geoteknik*, no. December. 2023.

[11] Akbar, “Analisis Sedimentasi Pada

Bendung Awo Kabupaten Wajo," *J. Karajata Eng.*, vol. 3, no. 1, pp. 44–51, 2023, doi: 10.31850/karajata.v3i1.2058.

[12] joseph E. Bowles, "Physical_and_Geotechnical_Properties_of.pdf," 1989.

[13] P. O. S. I. B. BBWS BRANTAS, "Laporan PPK OP SDA II BBWS BRANTAS.pdf," 2023.

[14] Adib, "Analisis Daya Dukung Aksial Tiang Tekan Hidrolik Diameter 60 cm dengan Menggunakan Metode Elemen Hingga pada Proyek Gedung Rawat Inap Tower - 1 Rs Haji Medan (Berdasarkan data BH-3)," vol. 6, no. 2, pp. 198–206, 2025, doi: 10.51988/jtsc.v6i2.304.

[15] SNI 8460 :, *Standar Nasional Indonesia 8460 : 2017 Persyaratan Perancangan Geoteknik*, vol. 8460. 2017.

[16] Rizky, "Analysis Of The Axial Bearing Capacity And Settlement Of Bored Pile Foundations Using The Finite Element Method (Case Study : Construction Of The Sumatera Main Stadium)," vol. 7, no. 1, pp. 371–377, 2026.