

Retaining Wall Design as a Landslide Disaster Mitigation Effort on the Enim River South Sumatra, Indonesia

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Abstract: This research focuses on analyzing the stability of three types of retaining walls cantilever, gravity, and sheet pile to address landslide risks along the Enim River in Tanjung Karang Village, Muara Enim Regency. The village is prone to landslides due to high riverbanks and unstable soil conditions exacerbated by erosion and settlement encroachment. To mitigate these risks, retaining walls are crucial in maintaining slope stability and preventing further erosion. The study utilized Windows Forms methods to perform numerical simulations and evaluate key factors such as the safety factor, sliding resistance, overturning resistance, bearing capacity, and material strength of the designed walls. The cantilever retaining wall design proved effective, achieving safety factors for overturning (1.80), sliding (1.51), and bearing capacity (1.31), making it suitable for implementation at the study location. However, the gravity retaining wall, despite meeting safety requirements for overturning (1.72) and bearing capacity (1.35), failed in sliding, with a safety factor of 1.49, indicating it is not appropriate for this case due to insufficient sliding resistance. The analysis of the sheet pile retaining wall focused on embedment depth and material quality. A steel sheet pile with a length of 9 meters, an embedment depth of 4.82 meters, and material properties of $F_y = 450$ MPa and $E = 2.1 \times 10^5$ MPa was determined to be a feasible solution. The findings conclude that both cantilever and sheet pile retaining walls can effectively mitigate slope instability and riverbank erosion, while the gravity retaining wall is not suitable for the given conditions. These results provide valuable insights for future infrastructure development in landslide-prone areas.

Keywords: retaining wall, riverbank erosion, Enim River

1. Introduction

The residential area of Pulau Panggung Village faces directly onto the Enim River [1]. The condition of the settlements on the banks of the Enim River is very prone to landslides due to the geographical conditions of the riverbanks which are quite high from the river flow and the disruption of the stability of the driving and resisting forces that occur on a cliff [2]. Erosion at the foot of the cliff, increased load on the top of the cliff due to the encroachment of settlements on the riverbank, and poor cliff drainage so that surface water that should be drained out of the cliff are some parameters that add to the load on a cliff [3]. If these things are not addressed, landslides can cause significant losses [4]. This condition requires handling in terms of infrastructure development. Infrastructure development that can overcome riverbank erosion is highly needed. One infrastructure that can overcome riverbank erosion is a retaining wall [5]. Physical handling of landslides requires a design to support the implementation of construction. Therefore, it is necessary to conduct good research and planning in realizing the construction of the Retaining Wall infrastructure in Tanjung Karang Village. A slope is a land surface with a certain height difference and slope, which causes the slope to seek its equilibrium if

the soil on the slope loses its shear strength [6]. Several factors influence slope stability, including high rainfall intensity [7], geological conditions, and land use [8]. In slope stability studies, the angle of inclination is a key parameter in calculating soil equilibrium on a slope. The greater the slope, the greater the shear force the soil must withstand to maintain slope stability [9].

Slopes can be natural or artificial. If the ground surface is uneven, the gravitational component will tend to move the soil downward. If the gravitational component is large enough, a slope collapse will occur. To determine whether a slope is stable or not, there is a safety factor that serves as a reference. If this value is met, then the slope is in a safe or stable condition. If it does not meet the requirements, then the slope is in a critical condition. The purpose of this analysis is to determine the safety factor of the potential landslide area. Safety factor is a crucial concept in slope stability analysis, representing the ratio between resisting forces and driving forces acting on a slope. It is mathematically expressed as:

$$SF = \tau / \tau d \quad (1)$$

SF is the safety factor, τ is the resisting force (kN/m^2), τd is the driving force (kN/m^2). A generally

accepted safety factor for slope stability or soil shear strength is between 1.2 and 1.5. According to Bowles [4], the safety factor value based on landslide intensity is as shown in Table 1. The stability of a retaining wall must be analyzed in terms of overturning, sliding, and soil bearing capacity. A safety factor is generally used to ensure that the structure is strong enough to withstand the applied loads, including live and dead loads, as well as the influence of groundwater [10]. Retaining walls are crucial structural elements employed to counteract lateral earth pressure, primarily utilized to prevent landslides in roadways, mining areas, and riverbanks [11]. Some types of retaining walls commonly used on riverbanks include gabion walls, reinforced concrete walls, sheet pile walls, and geocell retaining walls.

Tabel 1. Safety Factor Values Based on Landslide Intensity

Safety Factor (SF)	Occurrence
$SF < \sim 1,07$	Frequent Landslides (Unstable)
$1,07 < SF < 1,25$	Occasional Landslides (Crisis)
$SF > 1,25$	Rare Landslides (Stable)

Gabion walls, consisting of wire baskets filled with rocks, are very effective in reducing erosion while providing habitat for natural vegetation that can increase slope stability [12]. Reinforced concrete walls, on the other hand, are suitable for urban areas with high water pressure [13]. Geocell systems filled with local materials and planted with vegetation have also proven effective in reducing erosion and strengthening riverbanks [14]. Their design extends to locations with uneven topography dominated by high cliffs, utilizing cantilever retaining walls with safety measures against overturning, sliding, and bearing capacity [15]. Retaining walls must be designed to withstand various disturbances, including lateral movement, overturning, and bearing capacity failures. The collapse of retaining walls often stems from soft soil conditions at the construction site, leading to elevated groundwater levels, causing the retaining wall to fail [16]. Thorough and meticulous design calculations are essential for retaining walls. Utilizing specialized software can aid in the process, ensuring a retaining wall design that effectively resists overturning, sliding, and bearing capacity failures [17].

2. Methods

The village of Tanjung Karang, the subject of this study, is located in the southwestern part of Tanjung Agung District, Muara Enim Regency. The distance to the study site is approximately 40 km from the capital of Muara Enim Regency. This area is traversed by the Enim River, which divides residential areas and government-owned forests. The river's unpredictable flow rate poses a threat to the safety of residents and assets around the location. The research site is located

at coordinates $3^{\circ}49'48.9''S$ and $103^{\circ}47'19''E$, Tanjung Karang, Tj. Agung, Muara Enim Regency, South Sumatra. As shown in Figure 1, landslides have occurred in areas near the riverbanks, very close to residential homes. Three Standard Penetration Tests (SPT) have been conducted at the study location to determine the soil characteristics.

This study uses both primary and secondary data as input for analysis. The primary data collected from the field include slope contour data to determine the topography of the area and soil data to understand the characteristics and behavior patterns of the soil around the study location.



Figure 1. Research location and soil testing sample points

The processing of contour and soil data refers to the results of topographic activities and soil investigations carried out in the initial stages. In addition to the data, information such as the conditions around the riverbanks and the loads present on the riverbanks need to be recorded as reference sources. The research is conducted through several stages. The first stage is identifying the causes of retaining wall structure failures. This is followed by collecting the necessary data for analyzing retaining wall structure failures, such as topographic data, soil investigation data around the retaining wall location, and data on nearby buildings. Then, data processing and interpretation are carried out to determine the dimensions and analysis of the retaining wall that has achieved the safety factor value. Finally, conclusions are drawn, and recommendations are provided for the discussed case study. The research stages can be briefly seen in diagram 2.

The selection of the type of retaining wall is highly dependent on the site conditions and technical considerations from geotechnical literature. The following is an explanation of the three types of retaining walls that are commonly used and the reasons for their selection based on site conditions and civil engineering literature references. Reasons for selecting the type of retaining wall are:

Stable soil conditions and not too deep for wall heights less than 4 meters, Availability of local materials and Sufficient land Because if the dimensions are large, a fairly large footprint area is also needed.

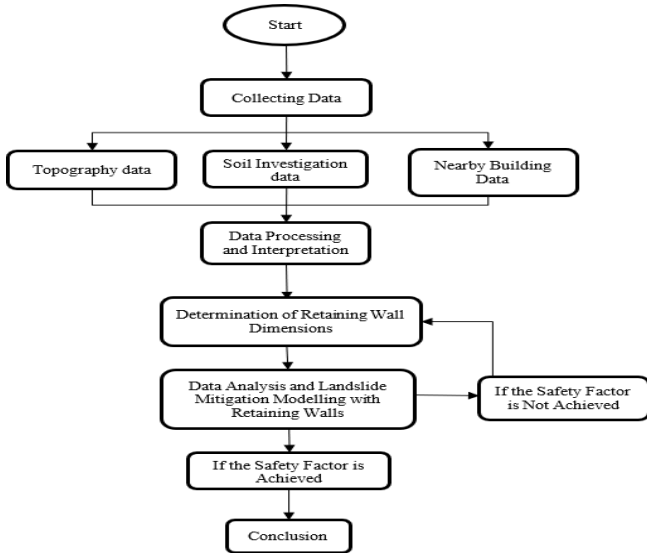


Figure 2. Research location and soil testing sample points

3. Result and Discussion

3.1. Slope Stability Analysis with Finite Element method

There were three soil investigation points around the banks of The Enim River. The soil investigation in this area consisted of deep boring with 10 meters in

depth, standard penetration test per 2 meters in depth and soil mechanics laboratory test. Each point of soil investigation was named as BH-01, BH-02 and BH-03.

The results of these soil investigation can be shown in figure 3. The simplified borlog of BH-01, BH-02 and BH-03 showed that the soil stratification in this area was divided into four (4) layers. The first layer of soil profile (0 – 3 meters in depth) was medium stiff clay with 10 blows/30mm SPT value. The second layer of soil profile (3 – 5 meters in depth) was stiff clay with 18 blows/30mm SPT value. And the third layer of soil profile (5 – 10 meters in depth) was very stiff clay with > 41 blows/30mm SPT value. And the last layer of soil profile was hard clay with > 60 blows/30mm SPT value.

The SPT value of each layer was used to interpreted soil parameter as the input data of finite element program. The required soil parameter in finite element program was unit weight of soil, permeability, soil stiffness, poisson ratio, cohesion and friction angle.

In this following table 2 below, it was the soil parameter of riverbanks slope. The riverbanks were modeled in finite element program based on topography data. The slope has inclination around 20°. The model and topography of riverbanks was shown in figure 3.

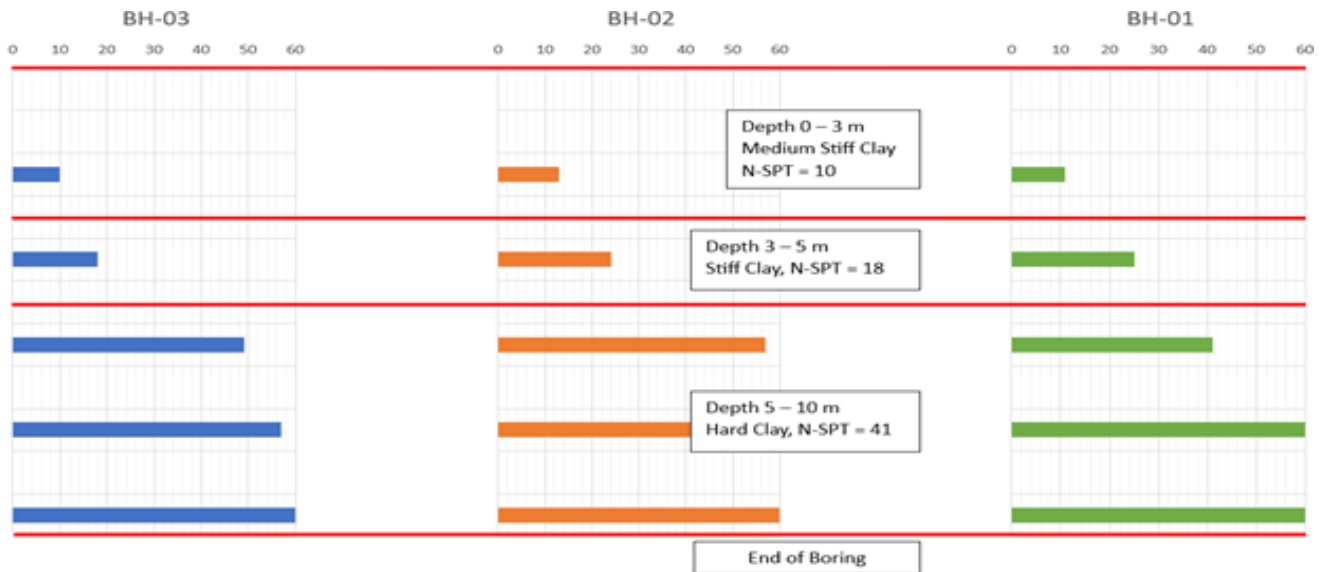


Figure 3. Geometry Model of Existing Slope

Table 2. Soil Parameter Based on SPT Value Interpretation

Depth	SPT Value (blows/mm)	Soil Type and Consistency	k (m/day)	γ_{sat} (kN/m ³)	γ_{unsat} (kN/m ³)	E'	c_u (kN/m ²)	ϕ (°)
0 – 3	10	Medium Stiff Clay	0.0008	16	18	6000	20	0
3 – 5	18	Stiff Clay	0.0008	17	19	10800	36	0
5 – 10	41	Very Stiff Clay	0.0008	18	20	24600	82	0
10 – 30	60	Hard Clay	0.0008	18	20	36000	120	0

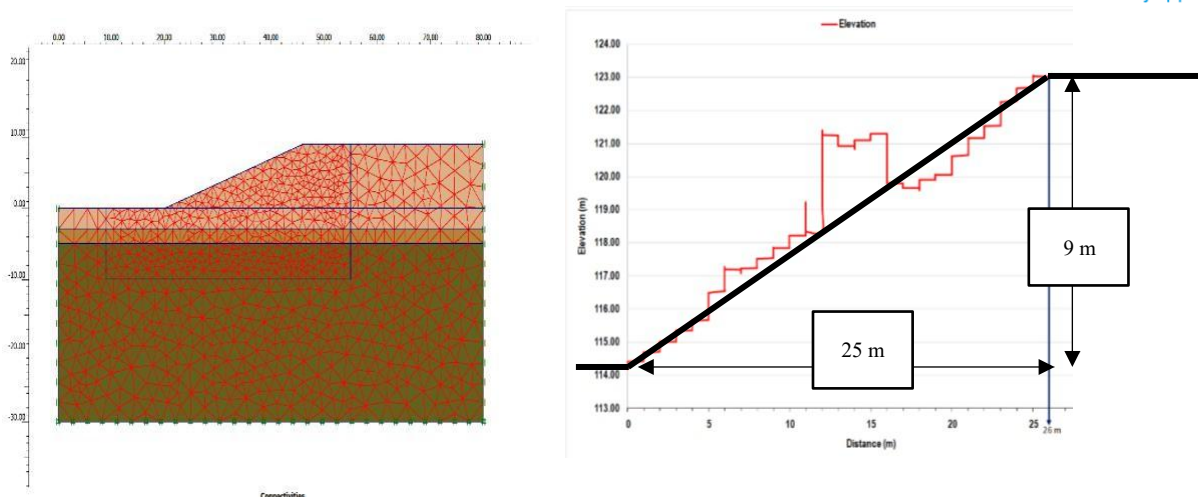


Figure 4. Geometry Model of Existing Slope

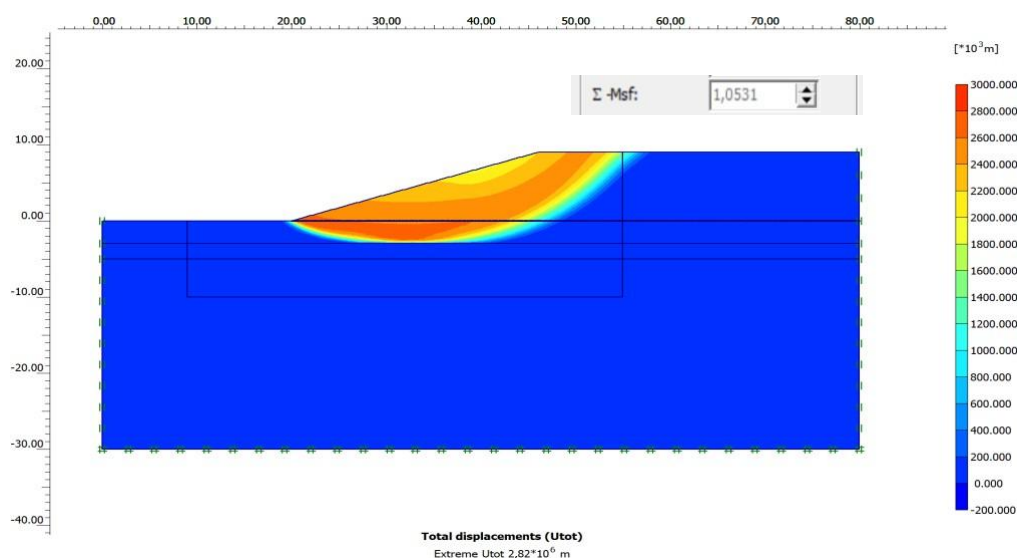


Figure 5. Estimation of Slope Failure (SF = 1.053)

Table 2. summarizes soil characteristics at varying depths, showing an increase in density, hardness, and stiffness as depth increases. The Standard Penetration Test (SPT) values rise from 10 to 60 blows/300mm from 0-3 meters to 10-30 meters, indicating denser soil with depth. The soil types range from Medium Stiff Clay near the surface to Hard Clay at greater depths. The permeability coefficient remains low at 0.0008 m/day across all depths.

Figure 4 illustrates the results of a slope modeling and cross-sectional analysis for assessing slope stability. The left side shows a finite element model, depicting different soil layers with colored regions and a triangular mesh used to simulate stress and strain responses within the slope. The right side presents a cross-sectional view of the slope, highlighting the elevation profile with a total height of 9 meters and a base length of 25 meters. The calculation of existing slope without any retaining wall showed that safety factor was still less than 1,5.

The result of safety factor calculation of existing

slope was shown in figure 5. Figure 6 presents the results of a total displacement analysis conducted on a slope stability model. The color scheme, ranging from blue (minimal movement) to red (maximum movement), visualizes the extent of displacement within the slope. Areas depicted in blue indicate regions with negligible movement, suggesting relative stability. Conversely, yellow to red areas signal zones with substantial displacement, particularly concentrated at the slope's upper sections. These areas are prone to significant deformation or ground movement. The maximum recorded displacement, represented by the Extreme Utot value of 2.82×10^{-6} meters, highlights the extent of movement within the model.

The safety factor (Msf) of 1.0531 positions the slope near the stability threshold. While a safety factor exceeding 1 typically denotes stability, the value's proximity to 1 necessitates further scrutiny, especially in regions exhibiting significant displacement. Based on these findings, the slope at the study site requires

remedial measures such as soil reinforcement or the construction of a retaining wall to ensure its long-term stability.

In this study, Three types of retaining walls will be analyzed: Counterfort retaining wall, Gravity retaining wall and Sheetpile. The retaining walls are planned to be located 10 meters from the edge of the slope, with a height of 4 meters for both the Counterfort and Gravity retaining walls. Below is an illustration of the planned positions of the retaining walls. This study successfully analyzed the stability of cantilever retaining walls, gravity walls, and sheet piles using Windows Forms methods. Based on the numerical simulation results, important data were obtained regarding the safety factor, shear force, overturning force, stability against bearing capacity, and material capacity of the walls.

Figure 6 illustrates the Safety Factor and Detailed Engineering Design of Retaining walls. The analysis results indicate that the designed retaining wall has

adequate safety factors, with an overturning factor of 1.80, a sliding factor of 1.51, and a bearing capacity factor of 1.31.

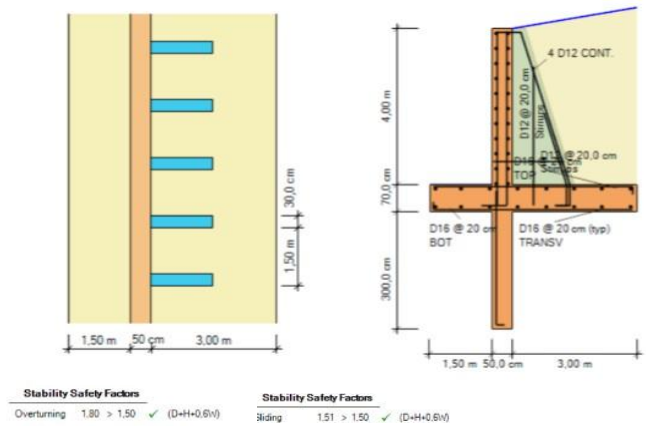


Figure 6. Counterfort Retaining walls model

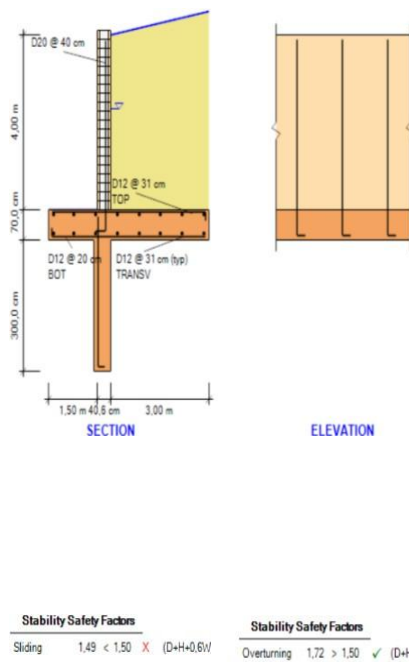
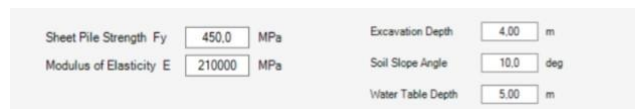


Figure 7. Gravity Retaining walls Model

From the above explanation, it can be concluded that this retaining wall can be applied. The wall height is 4 meters, with a foundation thickness of 0.7 meters and a wall thickness of 0.5 meters. The wall uses 12 mm steel bars for the stem and 16 mm steel bars for the foundation. There is a wing wall with a thickness of 0.3 meters, spaced 1.5 meters apart, and a shear key with a depth of 3 meters and a width of 0.5 meters. The concrete strength used is $F_c = 30$ MPa, and the steel strength is 420 MPa. Next, an analysis of the gravity retaining wall type will be conducted. Figure 7 illustrates the Safety Factor. The analysis results show that the designed retaining wall has adequate safety

factors, with an overturning factor of 1.72, a sliding factor of 1.49, and a bearing capacity factor of 1.35. However, as seen in Figure 9, this type of retaining wall fails in sliding, meaning the gravity-type retaining wall cannot be used in this case. With the same height of 4 meters, a foundation thickness of 0.7 meters, and a stem thickness of 0.6 meters, along with the same shear key, it still lacks sufficient resistance to sliding.

Next, an analysis was performed using the sheet pile retaining wall type. In the sheet pile analysis, the focus is not on the safety factor but on the depth of the sheet pile installation and the type and quality of the sheet pile material. As shown in Figure 8, the total



length of the sheet pile used is approximately 9 meters, with an embedment depth of 4.82 meters and an excavation depth of 4 meters. The material used is steel sheet pile with $F_y = 420$ MPa and a modulus of elasticity (E) of 2.1×10^5 MPa. The sheet pile retaining wall type can also be used in this case.

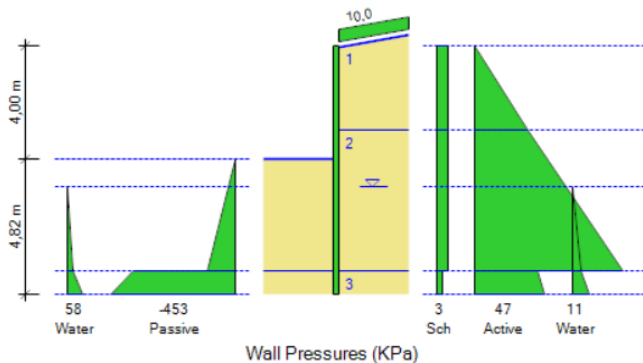


Figure 8. Sheetpile Retaining walls Model

4. Conclusion

This study successfully analyzed the stability of three types of retaining walls: cantilever, gravity, and sheet pile, using Windows Forms methods. Based on the numerical simulation results, the following conclusions can be drawn:

- The cantilever retaining wall design achieved adequate safety factors, with an overturning factor of 1.80, a sliding factor of 1.51, and a bearing capacity factor of 1.31. This indicates that the cantilever retaining wall is suitable for use in the study area.
- The gravity retaining wall, although designed with sufficient safety factors in overturning (1.72) and bearing capacity (1.35), failed in sliding with a factor of 1.49. Therefore, the gravity retaining wall type cannot be applied in this case, as it lacks the necessary sliding resistance.
- The sheet pile retaining wall was also analyzed, focusing on the depth of installation and material quality rather than safety factors. The results show that a sheet pile with a total length of approximately 9 meters, an embedment depth of 4.82 meters, and an excavation depth of 4 meters, made of steel with a yield strength of 450 MPa and a modulus of elasticity of 2.1×10^5 MPa, is a feasible solution for the given conditions.

Overall, the study concludes that while the cantilever and sheet pile retaining walls can be used effectively to address slope stability and riverbank erosion in Tanjung Karang Village, the gravity retaining wall is not suitable due to insufficient resistance to sliding.

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