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Landslide Management for Batu Tulis – Cross Bogor – Sukabumi Station Double Lane Project at STA 5+550

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Abstract

In the implementation of the St. Batu Tulis – Lintas Bogor – Sukabumi STA 5+550 project, a significant challenge arose with the occurrence of an avalanche during construction, attributing landslides to substantial land subsidence caused by the destabilization of the slope's soil or rocks. This disruption significantly impacted construction planning, particularly in terms of cost considerations. This study conducted a comprehensive comparative analysis of the stability of the original embankment slope and slopes reinforced with gabions (measuring 2m x 1m x 0.5m), sheet piles (type W-400 A-1000), and bored piles (size D600). To evaluate the stability, it was imperative to determine the safety factor (SF) and slope deformation under applied loads. The Plaxis 8.6 program was employed for the analysis, incorporating all relevant soil parameter data. Safety factor values were calculated as 1.67 for the gabion-bored pile combination slope, 1.62 for the sheet pile-reinforced slope, and 1.63 for the bored pile-reinforced slope. Estimated costs for slope strengthening were as follows: IDR 3,525,789,199.92 for sheet piles, IDR 2,180,309,258.00 for bored pile-gabion combination, and IDR 6,689,603,822.00 for bored piles alone. The budget for slope reinforcement with gabions proved more economical by IDR 1,345,479,941.92 compared to sheet piles and IDR 4,509,294,564.00 compared to bored piles. The reinforcement type selection was based on a cost analysis, prioritizing lower expenses while ensuring construction feasibility. Gabions offer advantages such as economical prices, flexibility, and simple construction methods, but they have drawbacks, including susceptibility of galvanized coated wire to water conditions with high salt or acid content and requiring a wide area for construction due to their large size. Sheet pile reinforcement is resistant to corrosion, durable, and has good performance, but it is unsuitable for supporting very high soil due to the requirement of a large cross-sectional area and not suitable for use in rocky soils due to piling difficulties.

Keywords: *Landslides, Slope Stability, Budget Design, Land Subsidence, Unit Price Analysis, Plaxis 2D*

1. Introduction

In implementing a construction project several risks may occur which are generally caused by uncertainty in the field which can affect both quality and quantity. Several events in the field are often related to uncertain field conditions which can cause some theoretical parameters to be inappropriate[1]. One of them is a landslide. Landslides are the process of moving soil masses due to gravity[2]. Landslides occur due to a disturbance in the balance of forces acting on the slope. As a result of the landslide, the ground shifts so that the construction above the slope collapses[3].

On the Implementation of the St. Batu Tulis – Lintas Bogor – Sukabumi STA 5+550 an obstacle occurred, namely an avalanche during the work implementation, so the implementer needed to carry out construction activities again (redo) to update and repair surrounding buildings located around the affected landslides. This has an impact on the cost of carrying out the work[4].

This research aims to find out the value of the safety factor and find out the Cost Budget Design by comparing the stability analysis of the original embankment slope, the slope reinforced with gabions combination bored pile, sheet pile, and bored pile[5]. The research used in this research uses a descriptive method with input variables: Cost Budget Design, Volume of Materials, and Safety Factor using Plaxis 2D.

2. Research Method

2.1 Cost Management

In carrying out construction, the cost factor is the main consideration because it usually involves large investment amounts that are susceptible to the risk of failure. Therefore, project costs need to be managed well so that they are possible overrun costs [6]. Costs consist of direct costs (direct cost) and indirect costs (indirect cost). Direct costs are the costs required to obtain resources that will be used to complete the project[7]. Meanwhile, indirect costs are costs required for a project that cannot be connected or are separated from certain activities on the project[8]. Cost management aims to complete projects according to a predetermined schedule, optimize the use of available resources, reduce production costs, and increase operational efficiency. Construction cost planning can be done by first studying the plan drawings and technical specifications[9].

Cost control is needed to maintain conformity between planning and implementation[10]. Control aims to ensure project costs do not exceed the implementation budget plan. The greatest opportunity to reduce the final cost of a project is at the feasibility study and planning stages.

2.2 Draft Cost Budget (RAB)

The Budget Plan (RAB) is a cost estimate carried out by a planning consultant, based on plan drawings and building specifications, the RAB is a composition of various sub-costs for construction and renovation, each work unit price in the RAB already contains components-cost components are generally based on work unit price analysis (AHSP) applicable in each region[11]. The cost budget plan is calculated by multiplying the volume of each type of work by the unit price of each work, and the total amount of work in the construction project is calculated to determine the overall project cost budget plan[12].

2.3 Slope Stability

Slope stability is one of the factors that needs to be considered as a measure of land safety. The purpose of slope stability analysis is to determine the safety factor of the landslide area[13], [14]. The safety factor is defined as the comparison value between the restraining force and the moving force.

Slope stability analysis can basically be viewed as the mechanism of motion of an object located on an inclined plane[15]. Slopes are formed by many variables and many uncertainty factors, including soil parameters such as soil shear strength, pore water pressure conditions, so when analyzing, simplification is always carried out with various assumptions.

2.4 Slope Safety Factor

Things that need to be considered in determining safety factor criteria are the risks faced, load conditions and parameters used in carrying out slope stability analysis. The risks faced are divided into three, namely high, medium and low[16]. Task an engineer examines the stability of a slope to determine its safety factor.

Table 1. Safety Factor Level

FK	Information
>1,5	Stable
1,07 > FK > 1,5	Critical
<1,07	Unstable

FK is equal to 1, then the slope is in a state of collapse. Usually 1.5 is an acceptable safety figure for shear strength for planning slope stability (SKBI-2.3.06, 1987). The level of safety factor values in Table 1 and the safety factor values for slopes according to SNI 8460:2017 as follows.

Table 2. Slope Safety Factor Value

Costs and risks of slope failure	Level of uncertainty	
	Low*	Height**
Repair costs are comparable to additional costs for designing more conservative slopes	1,25	1,5
The repair costs outweigh the additional costs of designing more conservative slopes	1,5	2.0 or more

*The level of uncertainty in the analysis conditions is categorized as low, if the geological conditions can be understood, the soil conditions are uniform, the soil investigation is consistent, complete and logical to the conditions in the field.
**The level of uncertainty in the analytical conditions is categorized as high, if the geological conditions are very complex, soil conditions vary, and soil investigations are inconsistent and unreliable.

2.5 Gabions

Bronjong kawat is a box made of woven steel wire coated with zinc which is filled with stones to prevent erosion installed on the banks of cliffs, river banks, the weaving process using machines[17]. Gabion or gabions, made from a pile of rectangular woven wire and filled with boulders (boulder). The dimensions of gabions are more or less the same as gravity type retaining walls, with a base width of approximately 0.5H-0.7H[18].

The advantages of gabions are that they are easy to obtain, installation does not require using a lot of heavy equipment, they are more flexible so it is easy to follow the movement of the ground beneath them without having to damage the basic construction, reduces the risk of landslides because the piles of stones inside these gabions allow water to flow in between them so that Soil pressure will be reduced thereby reducing the risk of landslides, the price of gabions is more economical[19].

2.6 Sheet Pile

Sheet pile is a structure designed and built to withstand lateral pressure (horizontal) land. The lateral soil pressure behind the soil retaining wall depends on the shear angle in the soil and cohesion (the attractive force between soil particles)[20]. The lateral pressure works from the top to the bottom of the soil retaining wall. When the installation projectsheet pile If this is not planned properly, then ground pressure can push constructionsheet pile thus causing construction failures and landslides[21].

Construction sheet pile It is arranged in the shape of a wall consisting of several sheets of sheet pile which are driven into the ground, to hold up piles of soil or land that is sloping.Sheet pile arranged as a soil retaining structure on a highway cliff, utilizationsheet pile as embankments in river flows, earth retaining structures in excavations, and sloping earth retaining structures so that the land does not slide[22].

Sheet pile Can be used on sandy or clay soil. If the subgrade has large cohesion, then on the contrary the soil adhesion will be small, sosheet pile easy to stake or remove again[23]. However, if the subgrade is granular soil, there will be friction at the seams sheet pile will cause a slowdown when driving or pulling back.

2.7 Bored Pile

From the stability analysis of the slope with the potential for landslides, there is a reinforcement method that will be tested to enhance the slope's safety factor, namely using Bored Pile reinforcement. Bored Pile is a type of foundation that begins with soil drilling, piles into the drilled hole for casting[24]. Iron pipes are installed in the soil to act as retaining walls for the hole; when the casting is completed, these pipes are withdrawn. Large pile bases are utilized in hard soil or soft rock to ensure high load-bearing capacity.

2.8 Program Plaxis

Program Plaxisnamely a program aimed at analyzing deformation and stability in the field of geotechnical engineering[25]. The preparation uses a special method of elements and development. The aim of developing the Plaxis program is so that the element method can be used and applied in river embankment analysis more easily, especially in soft soil. This program can determine the fineness of these elements[26].

The level of refinement functions to influence the calculation results to be more accurate. Models that can be done graphically in an easy way are potentially easy to create models of complex elements that can be done quickly, while the various existing facilities can be used to explain them in detail.

3. Method

The method used in this research is quantitative descriptive with input variables, namely Cost Budget Design, Material Volume, and Safety Factor use Plaxis 2D. References obtained from literature studies will be used as references and comparisons for this research[27]. This research is intended to evaluate events during the construction phase when landslides occur which cause disruption to construction planning, especially in the cost aspect.

In this study, a comparison was conducted between the stability analyzes of the original embankment slope and the embankment slope reinforced with a combination of gabions, bored piles, sheet piles, and bored piles. The analysis was performed using the Plaxis 8.6 program. Under these conditions, the soil is considered undrained, indicating that water cannot enter or exit the soil for a specific period due to changes in soil content leading to alterations in water tension. The dimensions of gabions used for slope reinforcement with code D with dimensions of 2 meters long x 1 meter wide x 0.5 meters high.Meanwhile, reinforcement with sheet piles uses type W-400 A-1000.

To assess the stability of the current slope, it is essential to ascertain the safety factor (SF) and slope deformation under applied loads. The initial analysis was conducted using the Plaxis 8.6 program, incorporating all soil parameter data. Subsequently, a comparative cost analysis was performed between reinforcement using gabions and reinforcement using sheet piles, while the bored pile modeling utilized D600 with a depth of 14 meters.

4. Findings

In this research, the data used in this research is secondary data obtained from PT. B, which is in the form of soil parameter data for each layer, can be determined by carrying out lab tests that refer to the Unified soil classification system. Soil parameter data has been obtained from drill log data and lab tests carried out by PT. B. Based on the attached borlog data, the average value is taken as soil data for analysis needs.

4.1 Soil Test Results

Field test results are used to determine the soil layer profile at the project location. Soil profiles are created based on the same soil type and adjacent N-SPT values. The soil parameters used in the analysis were taken from the average borlog results and reinforced with the results of back analysis (back analysis). The following are the soil parameter values.

PARAMETER TANAH									
Layer	Deskripsi	Batas Elevasi Lapisan (m)	Tebal (m)	NSPT	γ_m (kN/m^3)	Undrained Condition			
						c_u (kPa)	ø (...^{0})	Eu (kPa)	vu
1	Silty CLAY (medium)	0 - 7	7	4	17.00	26.80	0	5360	0.30
2	Silty CLAY (stiff)	7 - 11	4	10	19	67.00	0	13400	0.30
3	Gravel (very dense)	11 - 14	3	60	20.00	0.00	42	45960	0.35
4	Clayey SILT (very stiff)	14 - 18	4	16	19.00	107.20	0	21440	0.30
5	Clayey SILT (hard)	18 - 25	7	36	20.00	241.20	0	48240	0.30
6	Gravel (very dense)	25 - 35	10	60	20.00	0.00	42	45960	0.35

Figure 1. Soil Parameter Values

4.2 Loading

Traffic load is the vehicle load that is transferred to the road pavement. The traffic load used in this case study is class I roads with a traffic load of 15 kPa or 15 kN/m2 and an off-road load of 10 kPa or 10 kN/m2. Class I public roads generally function to serve local transportation or residential roads with a load not exceeding that of class I roads.
∑ Distributed Load = Traffic load + House load on slope area = 15 + 10 = 25 kPa.

4.3 Modeling Unreinforced Slopes

To determine the stability of the existing slope, it is necessary to know the safety figure (SF) and slope deformation when loading is applied. The analysis was first carried out using the Plaxis 8.6 program by entering all geotechnical soil parameter data. The original slope conditions are as follows.

a) Slope height: 10 m
b) Slope Length: 100 m
c) Load on the surface of the ground: 25 kPa
d) Slope angle: 45º

Modeling of unreinforced slopes can be seen in the following picture.

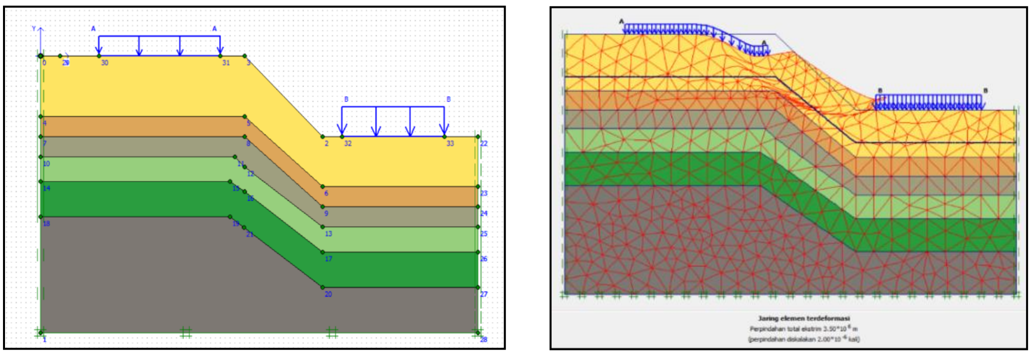

Figure 2. Modeling Unreinforced Slopes

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The security number value obtained from the analysis results using the program plaxis of 1.11. This value is a safety factor that occurs after loading in the form of traffic loads and house loads in slope areas. Based on SNI 8460 (2017), the slope is declared unsafe because the SF value of 1 is lower than the requirement, namely 1.5. So it is necessary to strengthen the slope to increase the value of the safety factor.

4.4 Reinforcement Slope Modeling *Sheet Pile*

The design of slope stability utilizing sheet piles is conducted based on the material properties obtained from the results of boring tests. This design aims to achieve a safe safety factor value. According to the N-SPT data, as illustrated in Figure 1, it is observed that the hard soil is situated at a depth ranging from 11.00 to 14.00 meters. Consequently, sheet piles are installed up to a depth of 14.00 meters. The outcomes of the slope analysis with the utilization of short-term sheet pile reinforcement are as follows.

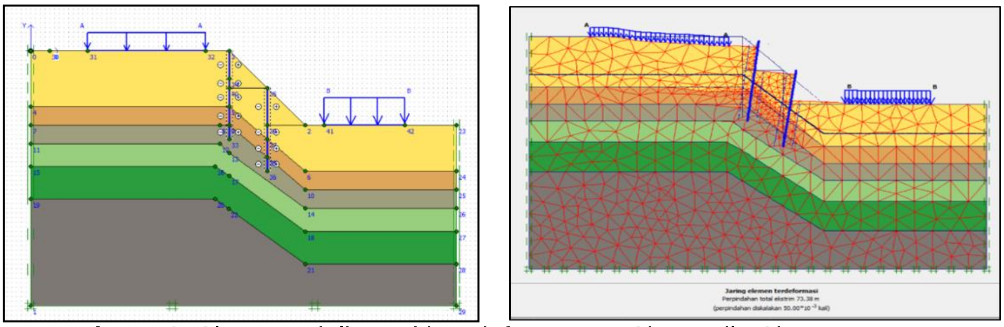

Figure 3. Slope Modeling With Reinforcement Sheet Pile Short-Term

The security number value obtained from the analysis results using the program *plaxis* of 1.62. This value is a safety factor that occurs after loading in the form of traffic loads and house loads in slope areas. Based on SNI 8460 (2017), the slope is declared safe because it has an SF value of 1.62, which is higher than the requirement, namely 1.5.

The results of the slope analysis utilizing sheet pile reinforcement for the long term are presented in Figure 4 below.

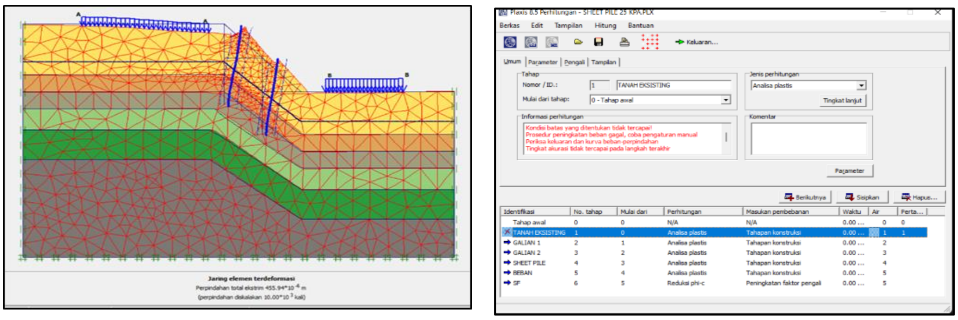

Figure 4. Deformed Mesh On Reinforced Slopes Sheet Pile Long Term

From the results of the analysis of long-term slope strengthening with sheet piles, it is known that the soil collapsed.

4.5 Modeling of Slope with Gabion Reinforcement Combined with Bored Piles

The gabion model utilized has a height of 9 m. Considering the height and maintaining a width of 6 m in the slope area, we employ gabion reinforcement with Code D, featuring

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dimensions of 1 m x 2 m x 0.5 m, and the bored pile size used is D600. The outcomes of the slope analysis using gabion reinforcement are presented below.

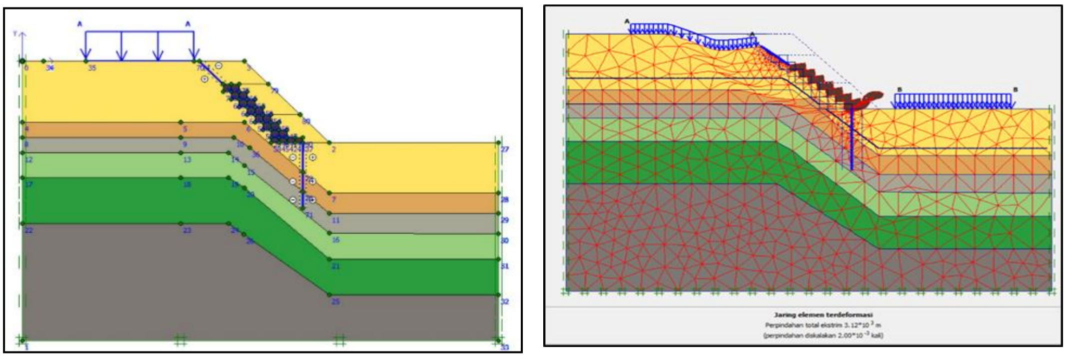

Figure 5. Slope Modeling with Short-Term Gabion Reinforcement Combined with Bored Piles

The security number value obtained from the analysis results using the program *Plaxis* of 1.67. This value is a safety factor that occurs after loading in the form of traffic loads and house loads in slope areas. Based on SNI 8460 (2017), the slope is declared safe because it has an SF value of 1.67, which is higher than the requirement, namely 1.5.

The results of the slope analysis using gabion combined with bored pile reinforcement for the long term are presented in Figure 6 below.

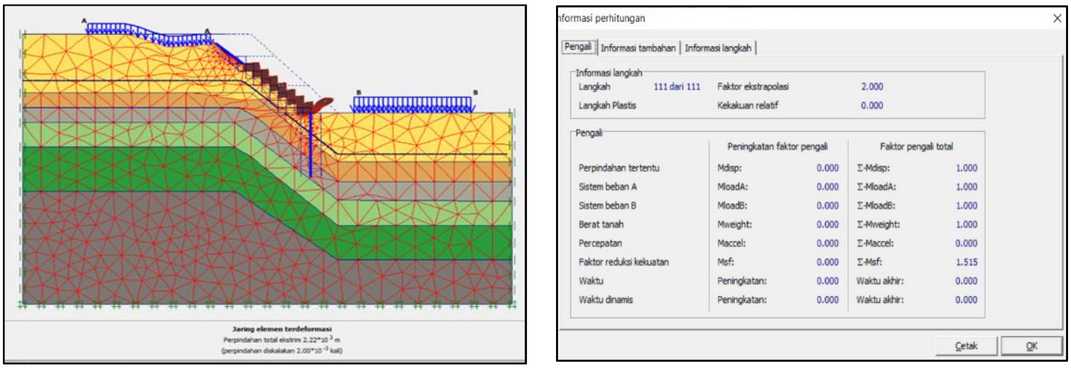

Figure 6. Slope Modeling with Long-Term Gabion Reinforcement Combined with Bored Piles

The safety factor value obtained from the long-term Plaxis analysis is 1.51, as shown in Figure 6. This value represents the safety factor after the application of loads such as traffic loads and residential loads in the slope area. According to the SNI 8460 (2017) standard, the slope is considered critical as it has an SF value of 1.51, which slightly exceeds the requirement of 1.5.

4.6 Slope Modeling with Bored Pile Reinforcement

The slope stability design using bored piles is carried out based on the material properties obtained from the results of boring tests. This design aims to achieve a minimum slope safety factor of 1.5. Utilizing the Plaxis 2D program, this modeling is analyzed to assess the impact of bored pile reinforcement on the slope and determine the slope's safety factor. The bored pile modeling employed D600 with a depth of 14m. The results of the slope analysis using bored piles are as follows.

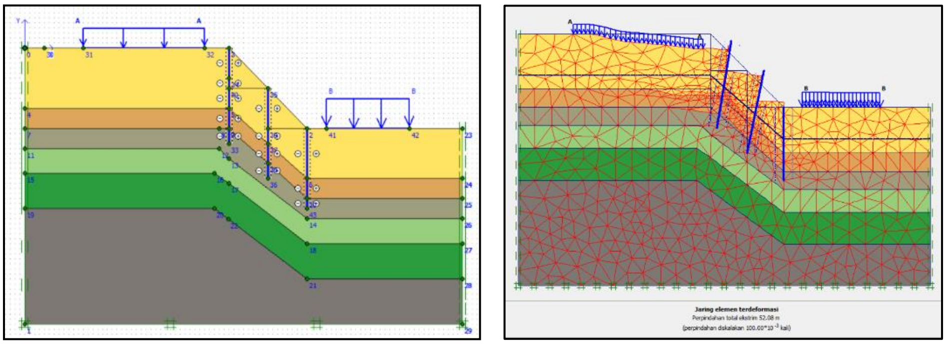

Figure 7. Slope Modeling with Short-Term Bored Pile Reinforcement

The security number value obtained from the analysis results using the program *Plaxis* of 1.63. This value is a safety factor that occurs after loading in the form of traffic loads and house loads in slope areas. Based on SNI 8460 (2017), the slope is declared safe because it has an SF value of 1.63, which is higher than the requirement, namely 1.5.

The results of the slope analysis using bored pile reinforcement for the long term are presented in Figure 8 below.

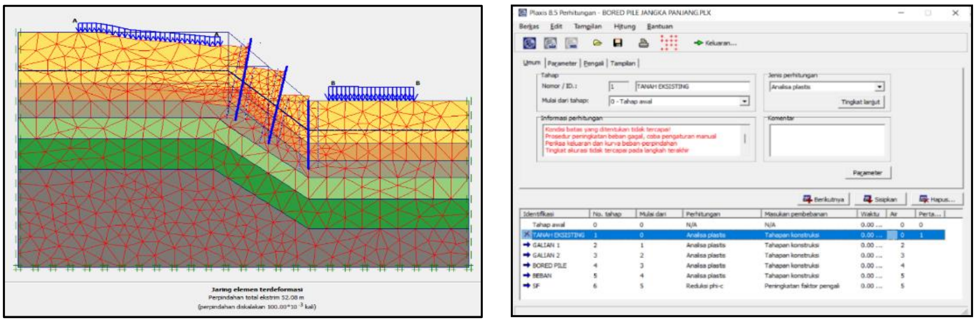

Figure 8. Deformed Mesh on Slope with Long-Term Bored Pile Reinforcement

From the results of the analysis of long-term slope strengthening with bored piles, it is known that the soil collapsed.

4.7 Slope Strengthening Cost Analysis

Cost calculations were carried out for both types of slope reinforcement, this aims to find a comparison of effectiveness and efficiency between the two designs. Cost budget planning is carried out based on volume calculations from the reinforcement design and unit price analysis that has been made.

4.8 Volume and Unit Price Analysis of Slope Strengthening Using *Sheet Pile*

Volume of slope reinforcement using materialssheet pile This is done by calculating the volume of work followed by analyzing the unit price of each work item. The following is a summary of the calculation of the volume of slope strengthening work using sheet pile.

Based on volume calculations and unit price analysis, the total cost of slope reinforcement is obtained using sheet pile as follows.

Table 3. Slope Strengthening Cost Budget Plan Using Sheet Pile

No	Works	Unit	Volume	Unit price	Total
	Mobilsasi dan Demobilisasi	ls	1	752.000.000,00	752.000.000,00

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1	Procurement of Sheet Pile	btg	64	11.400.000,00	729.600.000,00
2	Sheet Pile Erection	m	1152	216.295,22	249.172.088,92
3	Anchorage Jobs	m	580	609.523,00	353.523.340,00
4	Beam Capping Work				
a.)	Bobokan Head Pile	m³	55,81	109.300,00	6.100.033,00
b.)	Formwork	m²	909,60	155.000,00	140.988.000,00
c.)	K300 Concrete	m³	252,34	951.100,00	240.000.574,00
d.)	Reinforcing	kg	33031,39	10.100,00	333.617.039,00
e.)	Soil excavation	m³	4624,65	104.000,00	480.963.600,00
f.)	Landfill	m³	910,15	263.500,00	239.824.525,00
TOTAL DIRECT COSTS					3.525.789.199,92

Based on the budget plan table for slope reinforcement construction costs using sheet pile amounting to IDR. 3,525,789,199.92.

4.9 Volume and Unit Price Analysis of Slope Strengthening Using Gabions Loading

The calculation of the volume for slope reinforcement using gabion material involves determining the quantity of work and subsequently analyzing the unit price for each work item. Below is a summary of the volume calculation for slope strengthening work using gabion combined with a gabion. Additionally, an analysis of the unit price per cubic meter of slope strengthening work using gabions is provided.

The total cost of slope strengthening using Gabion combined with Bored Pile is determined based on volume calculations and unit price analysis, as follows.

Table 4. Cost Estimation for Slope Strengthening Using Gabion Combined with Bored Pile

No	Works	Unit	Volume	Unit price	Total
1	Gabion Work	m³	512	1.524.650,00	780.620.800,00
2	River Stone Installation Work				
a.)	Kali Stone Couple	m³	46,06	1.000.000,00	46.060.000,00
b.)	Kali Batu Siar Finishing	m²	153,52	95.000,00	14.584.400,00
c.)	Installation of PVC pipe'2	m	11,00	19.800,00	217.800,00
3	Pile Cap Work				
a.)	K-175 Work Floor Casting	m³	6,24	864.200,00	5.392.608,00
b.)	Reinforcing	kg	4943	10.100,00	49.924.300,00
c.)	Formwork	m³	213,25	155.000,00	33.053.750,00
d.)	K-350 casting	m³	97,05	986.600,00	95.749.530,00
4	D60 Bored Pile Work				
a.)	Drilling Diameter 60 cm	m	238	737.000,00	175.406.000,00
b.)	Reinforcing	kg	10610	10.100,00	107.161.000,00
c.)	K-350 casting	m³	65,97	986.600,00	65.086.002,00
d.)	Bobokan Head Pile	m³	3,96	109.300,00	432.828,00
5	Temporary Sheet Pile Work				
a.)	Sheet Pile Erection	m	1380	158.800,00	219.144.000,00

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b.)	Sheet Pile Removal	m	1380	197.000,00	271.860.000,00
c.)	Sheet Pile Rental	mount	120	1.087.100,00	130.452.000,00
d.)	Sheet Pile Mobilization and Demobilization	ls	120	361.500,00	43.380.000,00
e.)	Procurement of Geotextile Separator	m²	999,05	14.800,00	14.785.940,00
f.)	Installation of Geotextile Separator	m²	999,05	22.000,00	21.979.100,00
6	Soil excavation	m³	1.009,80	104.000,00	105.019.200,00
TOTAL DIRECT COSTS					2.180.309.258,00

Based on the table of construction cost budget plans for strengthening slopes using gabions kombinasi bored pile amounting to IDR. 2,180,309,258.00

4.10 Volume and Unit Price Analysis of Slope Strengthening Using Bored Pile Loading

Volume of slope reinforcement using materialssheet pile This is done by calculating the volume of work followed by analyzing the unit price of each work item. The following is a summary of the calculation of the volume of slope strengthening work using bored pile.

Table 5. Slope Strengthening Cost Budget Plan Using Bored Pile

No	Works	Unit	Volume	Unit price	Total
	Mobilization and Demobilization	ls	1	200.000.000,00	200.000.000,00
1	Pile Cap Work				
a.)	K-175 Work Floor Casting	m³	1152	216.295,22	249.172.088,92
b.)	Reinforcing	kg	14829	10.100,00	149.772.900,00
c.)	Formwork	m³	639,75	155.000,00	99.161.250,00
d.)	K-350 casting	m³	291,15	986.600,00	287.248.590,00
2	D600 Bored Pile Work				
a.)	Drilling Diameter 60cm	m	2268	737.000,00	1.671.516.000,00
b.)	Reinforcing	kg	100926	10.100,00	1.019.352.600,00
c.)	K-350 casting	m³	2563,75	986.600,00	2.529.395.750,00
d.)	Bobokan Head Pile	m³	3,96	109.300,00	432.828,00
3	Temporary Sheet Pile Work				
a.)	Sheet Pile Erection	m	1380	15.800,00	219.144.000,00
b.)	Sheet Pile Removal	m	1380	197.000,00	271.860.000,00
c.)	Sheet Pile Rental	btg/bln	120	1.087.100,00	130.452.000,00
d.)	Sheet Pile Mobilization and Demobilization	ls	120	361.500,00	43.380.000,00
e.)	Procurement of Geotextile Separator	m³	999,05	14.800,00	14.785.940,00
f.)	Installation of Geotextile Separator	m³	999,05	22.000,00	21.979.100,00
4	Soil excavation	m³	1009,80	14.800,00	14.945.040,00
TOTAL DIRECT COSTS					6.689.603.822,00

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4.11 Discussion

The results of the analysis carried out on slope strengthening usingsheet pile obtained a safety factor value of 1.62 with a total construction cost of IDR. (3,525,789,199.92). Meanwhile, strengthening slopes using gabions has a safety factor value of 1.67 with a total construction cost of IDR. (2,180,309,258.00) dan perkuatan lereng dengan menggunakan bored pile memiliki nilai faktor keamanan sebesar 1,63 dengan total biaya konstruksi sebesar IDR. (6,689,603,822.00). The following is a comparison of safety and cost factors.

Table 6. Comparison of Safety and Cost Factors

Strengthening Method	Safety Factor (Short Term)	Safety Factor (Long Term)	Cost
Sheet Pile	1,62	Collapse	3,525,789,199.92
Bored Pile Combination Gabions	1,67	1,515	2,180,309,258.00
Bored Pile	1,63	Collapse	6,689,603,822.00

Both slope reinforcements have met the safety factor requirements in accordance with SNI 8460:2017 regarding minimum requirements for permanent slope reinforcement. The value of the safety factor for both slopes is relatively the same, the choice of strengthening method used is based on previous research analysis and construction costs.

Strengthening slopes with gabion combined with bored pile is IDR 1,345,479,941.92 cheaper than strengthening slopes with sheet piles, and slope reinforcement using gabion combined with bored pile is IDR 4,509,294,564.00 cheaper than reinforcement using bored piles alone. The selection of the reinforcement type is based on a cost analysis, prioritizing lower expenses with the potential for straightforward construction and improved permeability.

5. Conclusion

In conclusion, the comparative research on cost management for landslide prevention along the St Batu Tulis - Cross Bogor - Sukabumi double track project at Sta 5+550 reveals valuable insights. The budget analysis demonstrates that slope reinforcement using gabion combined with bored pile proves to be a cost-effective alternative, amounting to Rp. 1,345,479,941.92 less than sheet piles and Rp. 4,509,294,564.00 less than bored piles alone. All three reinforcement methods meet safety factor requirements, as stipulated by SNI 8460:2017, for short-term applications. However, long-term analysis indicates potential soil failure for sheet piles and bored piles, highlighting the critical importance of additional reinforcement. The decision to employ gabion reinforcement is substantiated by its economic advantages, environmental friendliness, adaptability to field needs, and the ability to reduce active soil pressure. Nevertheless, consideration must be given to its limitations, such as susceptibility to high salt conditions or acid levels and the requirement for a substantial land area for construction. This research underscores the significance of a cost-based approach in selecting reinforcement types, prioritizing affordability and ease of implementation while acknowledging both advantages and limitations of the chosen method.

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6. Suggestions

Based on the analysis and discussion of the conducted research, several recommendations for further investigation emerge. Firstly, in the process of choosing criteria for slope strengthening, it is advisable to consider additional selection criteria to enhance the efficiency of selecting the appropriate reinforcement type. This consideration should encompass both construction and cost factors. Secondly, to enhance the robustness of slope modeling and analysis, a comparative study utilizing alternative geotechnical software, such as Geoslope and STABB, could be undertaken. Thirdly, when addressing slope reinforcement influenced by road traffic loads and anticipating annual degradation, it is essential to incorporate assumptions pertaining to critical conditions in the analysis. These recommendations aim to contribute to the refinement and advancement of slope reinforcement strategies.

References

[1] B. P. D. M. R. Anwar and A. Zacoeb, “Evaluation of Importance and Implementation of Work Quality in Building Construction”.

[2] S. Pranata, K. Hadi, M. H. R. Chakim, Y. Shino, and I. N. Hikam, “Business Relationship in Business Process Management and Management with the Literature Review Method,” *ADI J. Recent Innov.*, vol. 5, no. 1Sp, pp. 45–53, 2023.

[3] L. Ceferino, N. Lin, and D. Xi, “Bayesian updating of solar panel fragility curves and implications of higher panel strength for solar generation resilience,” *Reliab. Eng. Syst. Saf.*, vol. 229, p. 108896, 2023.

[4] J. Han and K. Akins, “Use of geogrid-reinforced and pile-supported earth structures,” in *Deep Foundations 2002: An International Perspective on Theory, Design, Construction, and Performance*, 2002, pp. 668–679.

[5] M. R. D. Pratama and M. R. A. Simanjuntak, “The study of the identification of using the supply chain to increasing financing efficiency of management project for building construction x in Jakarta,” in *IOP Conference Series: Materials Science and Engineering*, 2020, vol. 852, no. 1, p. 12018.

[6] H. Ahmad, M. H. Hoseini, A. Mahboubi, A. Noorzad, and M. Zamanian, “Effect of sheet pile wall on the load-settlement behaviour of square footing nearby excavation,” *Geomech. Geoengin.*, vol. 18, no. 2, pp. 149–167, 2023.

[7] F. Kalbuadi and B. E. Yuwono, “STUDY OF WORK UNIT PRICE PERMEN PUPR NUMBER 28 OF 2016 WITH PERMEN PUPR NUMBER 1 YEAR 2022 IN JU 1 RIVER EXCAVATION WORK,” *ADI J. Recent Innov.*, vol. 5, no. 1, pp. 93–99, 2023.

[8] E. J. Mihardja, S. Alisjahbana, P. M. Agustini, D. A. P. Sari, and T. S. Pardede, “Forest wellness tourism destination branding for supporting disaster mitigation: A case of Batur UNESCO Global Geopark, Bali,” *Int. J. Geoheritage Park.*, vol. 11, no. 1, pp. 169–181, 2023.

[9] I. P. Hastuty and A. M. Suwandi, “Slope stability analysis using sheet pile reinforcement with the Bishop method,” in *IOP Conference Series: Materials Science and Engineering*, 2020, vol. 851, no. 1, p. 12022.

[10] M. Mamun, R. Othman, and Z. Zulkifli, “Knowledge Management: Determine the Influencing Factors for Practicing at the Libraries in Bangladesh,” *J. Educ. Cult. Soc.*, vol. 14, no. 1, pp. 672–696, 2023.

[11] A. Akbar, A. Rehman, I. Ullah, M. Zeeshan, and F. E. A. Afridi, “Unraveling the dynamic nexus between trade liberalization, energy consumption, CO2 emissions, and health expenditure in Southeast Asian countries,” *Risk Manag. Healthc. Policy*, vol. 13, pp. 1915–1927, 2020, doi: 10.2147/RMHP.S272801.

[12] D. Permatasari, G. Maski, Susilo, and A. Manzilati, “Implementation of Poverty Reduction in North Maluku Province,” in *Modeling Economic Growth in Contemporary Indonesia*, Emerald Publishing Limited, 2022, pp. 123–133.

[13] S. Wahyuni, A. A. Taufik, and F. K. P. Hui, “Exploring key variables of port competitiveness: evidence from Indonesian ports,” *Compet. Rev. An Int. Bus. J.*, vol. 30, no. 5, pp. 529–553, 2020.

[14] D. Jonas, E. Maria, I. R. Widiasari, U. Rahardja, and T. Wellem, “Design of a TAM Framework with Emotional Variables in the Acceptance of Health-based IoT in Indonesia,” *ADI J. Recent Innov.*, vol. 5, no. 2, pp. 146–154, 2024.
[15] M. Ghozali, “Disaster Resilient Village Based on Sociocultural Aspect in Ponorogo,” *Mimb. J. Sos. dan Pembang.*, vol. 36, no. 1, pp. 63–73, 2020.
[16] S. T. Dewi, “Perencanaan Penjadwalan Pekerjaan Struktur Menggunakan Kombinasi Metode PERT Dan PDM (Studi Kasus: Proyek Pembangunan Gedung DLC UGM),” 2020.
[17] M. H. R. Chakim, M. Hatta, A. Himki, A. R. A. Zahra, and N. N. Azizah, “The Relationship Between Smart Cities and Smart Tourism: Using a Systematic Review,” *ADI J. Recent Innov.*, vol. 5, no. 1Sp, pp. 33–44, 2023.
[18] E. A. Beldiq, B. Callula, N. A. Yusuf, and A. R. A. Zahra, “Unlocking Organizational Potential: Assessing the Impact of Technology through SmartPLS in Advancing Management Excellence,” *APTISI Trans. Manag.*, vol. 8, no. 1, pp. 40–48, 2024.
[19] B. Bhima, A. R. A. Zahra, T. Nurtino, and M. Z. Firli, “Enhancing Organizational Efficiency through the Integration of Artificial Intelligence in Management Information Systems,” *APTISI Trans. Manag.*, vol. 7, no. 3, pp. 282–289, 2023.
[20] A. Hamidi and K. Abbeche, “Numerical analysis of bearing capacity of strip footing built on geogrid-reinforced sand slope over soft clay layer (revised version 3),” *Arab. J. Sci. Eng.*, vol. 45, no. 10, pp. 8269–8279, 2020.
[21] M. C. Saputra and E. Andajani, “Analysis of Factors Influencing Intention to Adopt Battery Electric Vehicle in Indonesia,” *ADI J. Recent Innov.*, vol. 5, no. 2, pp. 100–109, 2024.
[22] Y. Sun, S. Cao, H. Xu, and X. Zhou, “Application of distributed fiber optic sensing technique to monitor stability of a geogrid-reinforced model slope,” *Int. J. Geosynth. Gr. Eng.*, vol. 6, pp. 1–11, 2020.
[23] N. N. Rafiana, “Technopreneurship Strategy to Grow Entrepreneurship Career Options for Students in Higher Education,” *ADI J. Recent Innov.*, vol. 5, no. 2, pp. 110–126, 2024.
[24] M. M. Hajitaheriha, D. Akbarimehr, A. Hasani Motlagh, and H. Damerchilou, “Bearing capacity improvement of shallow foundations using a trench filled with granular materials and reinforced with geogrids,” *Arab. J. Geosci.*, vol. 14, pp. 1–14, 2021.
[25] W. Sejati and T. T. Akbar, “Optimization Study of Cropping Pattern in the Klakah Irrigation Area, Lumajang Regency, Using Linear Programming,” *ADI J. Recent Innov.*, vol. 5, no. 2, pp. 136–145, 2024.
[26] F. Luo, R. Huang, and G. Zhang, “Centrifuge modeling of the geogrid-reinforced slope subjected to differential settlement,” *Acta Geotech.*, vol. 15, pp. 3027–3040, 2020.
[27] D. Jonas, N. A. Yusuf, and A. R. A. Zahra, “Enhancing Security Frameworks with Artificial Intelligence in Cybersecurity,” *Int. Trans. Educ. Technol.*, vol. 2, no. 1, pp. 83–91, 2023.