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SWOT ANALYSIS IN PROJECT MANAGEMENT FOR SLOPE REINFORCEMENT USING THE GEOCELL METHOD

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Abstract

Slope stabilization is an important aspect of construction projects to ensure safety, execution efficiency, and long-term structural performance. This study aims to compare several slope reinforcement methods—namely geocell, hydroseeding, grass block, and shotcrete—based on time efficiency, cost effectiveness, and quality/safety performance, as well as to evaluate the geocell method using SWOT analysis and Weighted SWOT Analysis. The comparative results indicate that each slope reinforcement method has distinct characteristics; therefore, the selection should be aligned with project priorities. Based on the analysis, the geocell method provides the best and most balanced combination of cost, time, and quality among the alternatives. This method offers the lowest cost, a relatively efficient construction duration, and a sufficiently high level of quality and safety, although it does not always achieve the highest absolute performance. The SWOT analysis reveals that the main strengths of the geocell method lie in its economic advantage, flexibility for application under various slope conditions, and its significant ability to reduce erosion. However, its weaknesses include a relatively longer installation duration and the need for skilled labor, as the system performance is highly dependent on installation quality. The results of the Weighted SWOT Analysis yield an Internal Factor Score (IFS) of +1.38 and an External Factor Score (EFS) of +0.38, placing the geocell method in Quadrant I (Aggressive Strategy). This position indicates that strong internal capabilities support the optimal utilization of external opportunities. Therefore, the geocell method is considered highly feasible and is recommended as an effective, economical, and competitive slope stabilization solution compared to hydroseeding, grass block, and shotcrete methods in construction projects.

***Keywords**: Cost-time-quality analysis, SWOT analysis, geocell, project management, slope stabilization,*

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INTRODUCTION

Slope stability is a crucial factor in the success of construction projects, particularly for infrastructure such as dams, irrigation channels, roads, and hilly areas. Unstable slopes may pose risks of landslides, structural damage, increased repair costs, and project delays [1].

Therefore, selecting an appropriate slope reinforcement method constitutes a strategic decision in project management to ensure safety, quality, and long-term structural sustainability [2].

Slope reinforcement is a technical measure aimed at preventing slope failure and reducing landslide risks that may adversely affect user safety, infrastructure integrity, and rehabilitation costs [3]. With the rapid development of infrastructure in regions characterized by complex geotechnical conditions, the demand for effective, efficient, and sustainable slope stabilization methods continues to increase [4]. Various slope reinforcement methods have been implemented, including hydroseeding, grass block, shotcrete, and geocell, each of which exhibits specific advantages and limitations in terms of cost, construction duration, quality, and safety performance [5].

One of the widely developed slope reinforcement methods is geocell, which is a soil reinforcement system composed of three-dimensional polymer structures forming honeycomb-like cells [6]. This structure enhances soil stability through a confinement mechanism and more uniform load distribution, thereby increasing the slope safety factor and reducing surface erosion [7]. Compared to conventional reinforcement methods, geocell offers potential advantages in terms of application flexibility and cost efficiency, although it requires careful installation and skilled labor to ensure optimal performance.

In the context of construction project management, the selection of a slope reinforcement method represents a strategic decision-making process that directly affects project cost, schedule, quality, and risk performance. The chosen method must support the efficient achievement of project objectives while minimizing uncertainty during the implementation phase [8]. This approach assists project managers in formulating adaptive and efficiency-oriented strategies for selecting slope reinforcement methods that are aligned with overall project goals [9].

From a project management perspective, the successful implementation of the geocell method is determined not only by technical aspects but also by comprehensive project management practices, including planning, organizing, execution, and control [10]. In this context, SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats) serves as a strategic tool to identify internal and external factors influencing the successful application of a construction method and to support rational and systematic decision-making [11].

Based on this background, this study focuses on the selection of the geocell method as a slope reinforcement system using a SWOT analysis approach, while conceptually comparing it with other slope reinforcement methods, namely hydroseeding, grass block, and shotcrete. This approach is expected to provide a more systematic and rational basis for determining the most appropriate slope reinforcement method from both technical and project management perspectives.

RESEARCH METHODOLOGY

This study was conducted at the Karangnongko DAM, Bojonegoro Regency, with a focus on slope reinforcement works using the geocell method. The research adopts a descriptive mixed-methods approach, combining quantitative and qualitative analyses to obtain a comprehensive understanding of both technical and managerial aspects involved in the selection of slope reinforcement methods based on SWOT analysis.

Data Collection Techniques

Data was collected through a literature study by reviewing relevant books, journals, and references, as well as collecting project data, including project technical reports, cost data, and work duration, to obtain practical information related to the advantages and disadvantages of reinforcement methods. The researchers also conducted interviews. Project data for slope work was obtained by calculating the volume of the right side with an area of 992.985 m². The calculation of time and cost for the slope area used the total volume of the area.

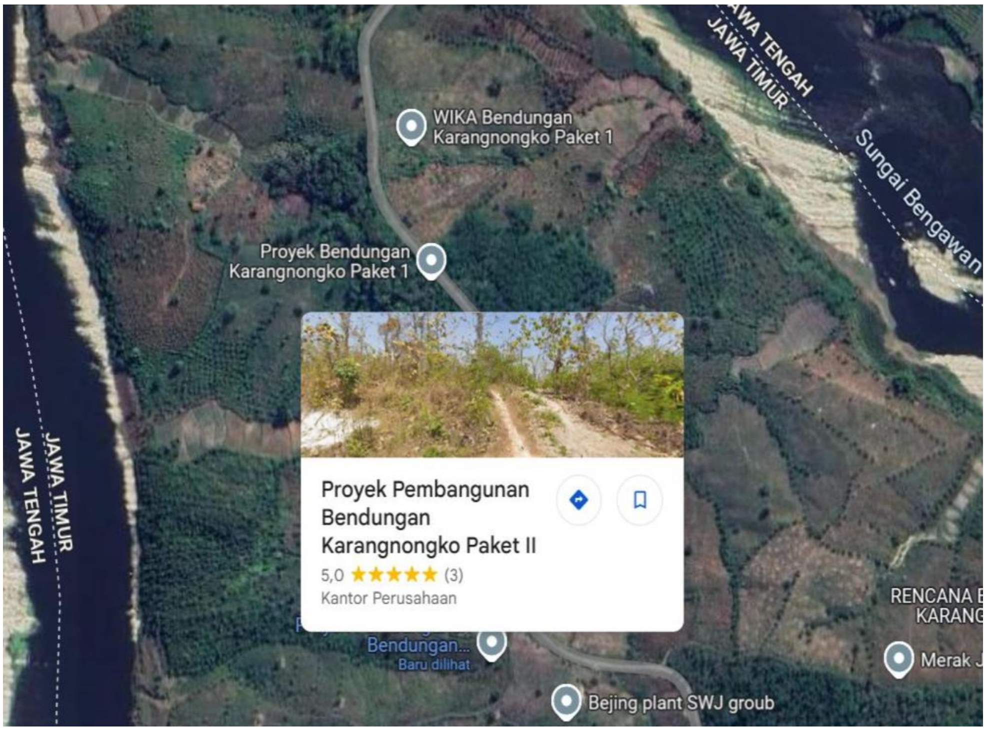

Figure 1. Location of the Study

The quantitative approach is applied to analyze numerical data related to the performance of slope reinforcement methods, including cost efficiency, construction duration, and quality/safety performance. These data are obtained from project documents, unit price analyses, and comparisons with alternative slope reinforcement methods. The results of the quantitative analysis serve as the basis for evaluating internal and external factors in the SWOT analysis.

Meanwhile, the qualitative approach is conducted through a descriptive analysis of the implementation of slope reinforcement works using the geocell method. Qualitative data are collected through field observations, reviews of technical documents, and input from project stakeholders. These data are used to identify internal factors (strengths and weaknesses) derived from the technical characteristics and execution of the geocell method, as well as external factors (opportunities and threats) influenced by environmental conditions, regulatory aspects, resource availability, and project execution risks.

All identified internal and external factors are subsequently mapped into the SWOT matrix. A Weighted SWOT Analysis is then performed by assigning weights and ratings to each factor to obtain the Internal Factor Score (IFS) and External Factor Score (EFS). The results of this analysis are used to determine the strategic position of the geocell method and to formulate recommendations for selecting the most appropriate slope reinforcement method from both technical and project management perspectives.

RESULTS AND DISCUSSION

The application of the geocell method in slope reinforcement is not only analyzed from a technical perspective, but also through a project management framework that includes cost, time, and quality. These three indicators are key elements in determining the success of a construction project [12].

Time Analysis

According to [13], the implementation of a construction project requires good time management because if this is neglected, there will be delays in the completion of the project.

Geocell Production Capacity

Geocells generally have a sheet length of approximately 3.36 meters. The bound range is around 330+-2.2mm, while the depth per cell can vary between 150mm and 200mm. The cell size is approximately 244 mm wide and 203 mm long. In one section, the number of cells can reach 150 or 300 mm, providing flexibility in adjustment depending on project requirements. In addition, the section area is expanded by a percentage of approximately 15+-1% or 30+-m, demonstrating its ability to accommodate changes in size and shape required in construction projects. These specifications reflect the design and flexibility of geocells in various applications, including soil reinforcement, surface protection, and slope stability [14].

The production capacity of installation using the geocell method with the assistance of an excavator is greatly influenced by the size of the work area, the type and size of the geocell, and the efficiency of the equipment and labor in the field [15]. Excavators are used to help level the ground, open and spread geocells, and fill the geocell cells with material (such as aggregate or fill dirt) more quickly and evenly. The use of excavators can significantly speed up the installation process, especially on large slopes with limited access. The following is a simulation of the production capacity calculation.

Production capacity/hour (Q1) $= \frac{V \times Fb \times Fa \times 60}{Ts1 \times Fv} = \frac{1{,}00 \times 1{,}10 \times 0{,}83 \times 60}{0{,}47 \times 1{,}1}$ (1)

$= 106{,}335$ m³/ hour

Equipment Coefficient/m³ $= \frac{1}{Q1}$ (2)

Duration $= \frac{Volume}{Production\ capacity} = \frac{10.052{,}718}{106{,}335}$ (3)

$= 201{,}7$ hour

In construction project management calculations, it is commonly assumed that one working day consists of 8 effective working hours. If the total working time is 94.539 hours, the project duration in working days is calculated using the following formula:

Duration (Day) $= \frac{Total\ working\ hours}{Working\ hours\ per\ day}$ (4)

$= \frac{94{,}539\ hours}{8\ hours}$ = 11,82 hours ≈12 days

Cost Analysis

Cost analysis is conducted to determine the total budget requirements for slope stabilization work using the geocell method. Cost calculations are based on the unit price of the work and the area of the slope to be reinforced[16].

According to Pratiwi [17], cost control is necessary to maintain consistency between planning and implementation. The objective of control is to ensure that project costs do not exceed the implementation budget plan. The greatest opportunity to reduce the final project cost is at the feasibility study and planning stages. What is needed to control costs is an implementation plan that addresses quality, volume, and unit prices of work obtained.

The Unit Price Analysis (AHSP) for slope surface retention work using geocells in construction projects must refer to official standards set by the government. In this case, the basis for the preparation of unit prices is the Circular Letter of the Director General of Construction No. 73 of 2023 concerning the Analysis of Unit Prices for Regulatory Work. This regulation provides complete guidelines on how to prepare unit price analyses, including the calculation of labor coefficients, equipment requirements, materials, analysis methods, and nationally applicable principles for preparing unit prices [18]. By referring directly to SE-Dirjen Bina Konstruksi No. 73/2023, the calculation of costs for geocell work becomes more standardized and accountable from both a technical and administrative perspective (Table 1).

Table 1. Analysis of Geocell Worker Unit Prices

No	Description	Unit	Quantity	Unit Price (Rp)		Total Price (Rp)	
I	**MATERIAL**						
1.	Geocell	m^2	1,0000	Rp	185.900,00	Rp	185.900,00
2.	Key lock	unit	2,0000	Rp	17.750,00	Rp	35.500,00
3.	Grass	m^2	1,0000	Rp	90.000,00	Rp	90.000,00
4.	Plant Fertilizer	m^2	0,0002	Rp	18.000,00	Rp	3,59
				Subtotal I		**Rp**	**311.403,59**
II	**WAGES/LABOR**						
1	Worker	OH	0,0074	Rp	94.400,00	Rp	701,76
2	Planter	OH	0,0045	Rp	106.700,00	Rp	475,92
3	Foreman	OH	0,0015	Rp	125.100,00	Rp	186,00
				Subtotal II		**Rp**	**1.363,67**
III	**EQUIPMENT**						
1	Excavator	Unit/ hour	0,0094	Rp	410.000,00	Rp	3.855,76
				Subtotal III		**Rp**	**3.855,76**
		Subtotal (I + II + III)				**Rp**	**316.623,02**
		Profit 10%				**Rp**	**31.662,30**
		Unit Price of Work				**Rp**	**348.285,00**

The unit price for slope surface reinforcement with geocells is set at Rp 348,285.00 per square meter. This value includes geocell materials, installation work, labor, and other supporting equipment. Furthermore, the slope surface area requiring reinforcement is 992.985 m². The calculation can be divided into three main components, namely material costs, labor costs, and equipment costs, which are then added together to obtain the total base cost before profit is added.

Prices for slope surface retention using geocells
= Total cost unit price (Rp) × Surface are
= Rp 348.285 × 992,985 m^2 = Rp 345.841.781

Security Factor Analysis

Safety factor analysis on slope surface retention using Slope/W software (part of the GeoStudio suite). This analysis was conducted to evaluate the effectiveness of slope surface retention methods in improving stability against potential landslides. The main focus of this discussion is on comparing the safety factor (SF) values between existing slope conditions and slopes that have been reinforced using the geocell method [19]. Modeling was carried out based on slope geometry data and geotechnical soil parameters based on secondary data (Table 2). GeoStudio is geotechnical software developed in Canada. In this study, this program was used to analyze slope stability. In analyzing slope stability in this software, we used the SLOPE/W menu, and the method used in this program was the Limit Equilibrium Method [20].

Table 2. Geocell Material Parameters

Parameter	**Nilai**
Material Model	Mohr-Coulomb
Unit Weight (γ)	19,5 kN/m³
Cohesion (c')	5 kPa
Phi (ϕ)	38°

Based on the results of the safety factor analysis using Slope/W for several slope surface retention methods, it can be concluded that the safety factor of the geocell method obtained a safety factor value of 1.683. And the method has a safety factor of ≥ 1.500, so it is feasible to use.

Comparison of Methods

Table 3 illustrates the comparison of the methods.

Table 3. Comparison of Methods

No.	Method	Time (Day)	Cost (Rp.)		Quality (Security Factors)
1	*Geocell*	12	Rp	345.841.780,73	1,683
2	*Hydroseeding*	4	Rp	1.903.549.266,05	1,706
3	*Grassblock*	3	Rp	491.365.718,45	1,643
4	*Shotcrete*	30	Rp	1.576.917.773,13	1,876

Based on the comparison of four slope reinforcement methods, it can be seen that each method has different characteristics in terms of implementation time, cost, and quality (Table 4). The Grassblock method is the fastest alternative with a duration of only 3 days and a medium cost of Rp 491,365,718.45, but it has the lowest safety factor of 1.643. The Hydroseeding method is the second fastest option (4 days), but requires the highest cost of IDR 1,903,549,266.05, although it provides a fairly good safety factor of 1.706.

The Geocell method takes 12 days with a relatively low cost of IDR 345,841,780.73 and a fairly high safety factor (1.683), thus offering a balance between cost and quality. Meanwhile, the Shotcrete method has the highest safety factor (1.876), but requires the longest time, namely 30 days, and a large cost of IDR 1,576,917,773.13. Overall, the choice of method depends heavily on the project's priorities: time efficiency, cost efficiency, or achieving the highest quality/safety.

Table 4. Normalized Results

Metodhs	Time (%)	Cost (%)	Quality (Factor) (%)
Geocell	24,49	8,01	24,36
Hydroseeding	8,16	44,08	24,7
Grassblock	6,12	11,38	23,78
Shotcrete	61,22	36,53	27,16

Based on the calculation and normalization results relative to the total values of each criterion, the geocell method exhibits the lowest cost contribution at 8.01% compared to other slope reinforcement methods. In terms of construction duration, geocell accounts for 24.49% of the total implementation time, which can be considered relatively efficient. Meanwhile, regarding quality, as represented by the safety factor, geocell achieves a value of 24.36%, indicating an adequate level of safety and a performance comparable to other methods. These results indicate that the geocell method provides an optimal balance between cost efficiency, construction time, and structural performance.

SWOT Analysis for Geocell Method

SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) in project management for slope reinforcement using the Geocell method is used to identify internal and external factors as a basis for developing a strategy for applying the Geocell method in construction projects. Table 5 presents the strengths, weaknesses, opportunities and threats from geocell methods using SWOT analyses.

Table 5. SWOT Analysis for the Geocell Method

Item	*Issue*
Weaknesses	- Longer construction time compared to Grassblock and Hydroseeding (12 days - Requires skilled labor for geocell panel installation. - Structural strength is not as high as Shotcrete (FK = 1.8)
Stength	- Lowest cost compared to other methods - High safety factor (SF = 1.683) - Flexible installation on various slope conditions - Effective in reducing surface erosion.
Opportunities	- Development potential in line with advances in geosynthetic technology - Can be combined with vegetation to increase ecological benefits - Tends to be chosen for large projects with limited budgets
Threats	- Risk of failure if installation is not precise - Very soft soil can reduce performance - Competition with other low-cost stabilization methods

It can be concluded that the Geocell method is the most effective choice overall. This is based on the balance between the three main aspects, namely time, cost, and safety factors. The Geocell method shows the lowest cost (8.01%), with a relatively fast implementation time (24.49%), and a fairly good safety factor (24.36%), thus providing the highest efficiency value when compared to other methods.

SWOT analysis is a strategic decision-making method that identifies strengths, weaknesses, opportunities, and threats. This method helps project managers understand the internal and external factors that influence the successful implementation of a technology or construction method.

At this stage, secondary data was collected and reviewed from the geosynthetic and slope stabilization literature, such as [21], Pokharel et al. and Bathurst & Jarrett [22], which discussed the performance, advantages, and limitations of Geocell. The information is then classified into four SWOT components, namely strengths, weaknesses, opportunities, and threats. The analysis is carried out interpretively to identify internal factors that affect Geocell performance, such as cost efficiency and the need for experts, as well as external factors such as technological developments and potential installation risks. The results of this identification were used to provide a comprehensive overview of the feasibility of applying Geocell in specific geotechnical conditions.

Results of Weighted SWOT Analysis for Geocell Method

Weighted SWOT Analysis is a strategic analysis method that develops the basic concept of SWOT (Strengths, Weaknesses, Opportunities, Threats) by assigning weights and ratings to each factor being analyzed. This approach aims to produce a more objective assessment of the relative contribution of various internal and external factors to the success of a project. The weights and ratings in the Weighted SWOT Analysis were determined by the researcher based on expert judgment involving project practitioners (engineers and consultants), and were supported by technical project data and a review of relevant literature (Table 6).

Table 6. *Weighted SWOT Analysis*

No	Faktor	Weight (W)	Rating (R)	Skor (W×R)
Strengths				
S1	Lowest cost compared to other methods	0,15	4	0,6
S2	High safety factor (SF = 1.683)	0,12	3	0,36
S3	Flexible installation on various slope conditions	0,1	4	0,4
S4	Effectively reduces surface erosion	0,13	4	0,52
	Total *Strength* Score	**0,5**		**1,88**
Weaknesses				
W1	Longer construction time (12 days)	0,1	2	0,2
W2	Requires skilled labor	0,08	2	0,16
W3	Lower structural strength than shotcrete	0,07	2	0,14
	Total *Weaknesses* Score	**0,25**		**0,5**
Opportunities				
O1	Advances in geosynthetic technology	0,09	3	0,27
O2	Can be combined with vegetation	0,08	4	0,32

O3	Selected for large projects with limited budgets	0,05	3	0,15
	Total *Opportunity* Score	**0,22**		**0,74**
Threats				
T1	Risk of failure if installation is not precise	0,07	2	0,14
T2	Very soft soil reduces performance	0,06	2	0,12
T3	Competition from other low-cost stabilization methods	0,05	2	0,1
	Total *Threat* Score	**0,18**		**0,36**

Based on the results of the Weighted SWOT Analysis, a Strength–Weakness value of 1.88 – 0.50 = +1.38 was obtained, indicating that the internal strengths of the Geocell method are more dominant than its weaknesses. In addition, the Opportunity–Threat value of 0.74 – 0.36 = +0.38 is also positive, meaning that external opportunities are still greater than the threats that may arise during implementation. The combination of these two positive values places the Geocell method in a very advantageous strategic position.

CONCLUSION

Based on the comparative analysis, each slope reinforcement method exhibits distinct characteristics; therefore, the selection of an appropriate method should be aligned with project priorities. This study evaluates three main aspects: time efficiency, cost effectiveness, and quality or safety level. The results indicate that the geocell method provides the most balanced combination among all evaluated alternatives. It offers the lowest cost, a relatively efficient construction duration, and a sufficiently high and competitive safety factor compared to other methods.

The SWOT analysis further confirms that the geocell method represents an effective and economical option for slope stabilization in construction projects. In terms of strengths, geocell demonstrates superior cost efficiency, flexibility in application across various slope conditions, and a significant ability to reduce surface erosion. Although the method has certain weaknesses, including a relatively longer construction duration and the need for skilled labor to ensure precise installation, these limitations can be effectively managed through proper project planning and control.

The results of the Weighted SWOT Analysis yield an Internal Factor Score (IFS) of +1.38 and an External Factor Score (EFS) of +0.38, positioning the geocell method in Quadrant I (aggressive strategy). This position indicates that the internal strengths of the geocell method strongly support the optimal utilization of external opportunities. Therefore, the application of the geocell method for slope stabilization is considered highly feasible and recommended due to its competitive advantages in terms of low cost, installation flexibility, and adequate safety performance compared to other methods.

Practically, the findings of this study provide important implications for construction project management, particularly in decision-making related to the selection of slope reinforcement methods. An integrated approach combining technical evaluation and SWOT analysis can assist project managers in selecting methods that are not only structurally safe but also cost- and time-efficient, thereby supporting optimal and sustainable project performance.

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