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The Effect of Ground Water Level on the Stability of Retaining Walls and Land Movement on the Lampa-Timbong Road Section, Banggai District, Banggai Laut Regency

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Abstract:
The Lampa–Timbong road section in Banggai Laut Regency has experienced ground movement and retaining wall instability due to fluctuations in the groundwater table during the rainy season. Rainwater infiltration increases pore water pressure and decreases effective stress, thereby reducing soil shear strength and triggering deformation or potential collapse. This study employed the Finite Element Method (FEM) using PLAXIS 2D to evaluate the effects of groundwater level variations on the stability and deformation of a cantilever retaining wall. The numerical modeling simulated groundwater levels ranging from the initial depth of –0.35 m up to +4.5 m, influenced by rainfall infiltration with an intensity of 0.01889 m/day. The soil, classified as MH (Inorganic Silt of High Plasticity) according to USCS and A-4 according to AASHTO, exhibits high plasticity, low permeability, and low bearing capacity. The analysis indicates that groundwater level rise significantly affects wall stability. Under the initial condition (–0.35 m), the safety factor was 1.604, with a total displacement of 0.0656 m, indicating a stable condition. As the groundwater level rose from +1 m to +4 m, the safety factor decreased from 1.388 to 1.033, while total displacement increased from 0.0875 m to 0.2931 m. The critical condition occurred at +4.5 m, where total failure of the retaining structure was observed. Therefore, the retaining wall stability is highly sensitive to groundwater fluctuations, with the safe limit reached at approximately +4.0 m, where the safety factor approaches the minimum allowable value.
Keywords: *Groundwater fluctuation; Retaining wall stability; Finite Element Method (FEM); Safety factor; Rainfall infiltration*

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I. INTRODUCTION

The Lampa–Timbong Road section in Banggai District, Banggai Laut Regency, is one of the vital infrastructures that connects several strategic areas and serves as a crucial route for community mobility and goods distribution. Based on field observations and reports from local residents, a segment of this road has experienced ground movement that threatens both the road's stability and the existing retaining wall. This phenomenon is strongly suspected to be related to fluctuations in the groundwater table, which rises sharply during the rainy season.

Rainfall is one of the most influential external factors affecting groundwater dynamics, especially in tropical regions with high rainfall intensity such as Banggai Laut Regency. When heavy and prolonged rainfall occurs, water infiltrates into the soil, raising the groundwater table. According to Das (2010), rainfall infiltrates the soil pores, and once the saturation capacity is reached, the groundwater level rises significantly.

The rise of the groundwater table due to rainfall leads to an increase in pore water pressure. Based on the theories of Bowles (1997) and Craig (2004), an increase in pore water pressure reduces the effective stress of the soil, which is the main component maintaining shear strength. Consequently, the soil's ability to resist external forces such as self-weight, traffic loads, or lateral pressures from structures decreases.

Budhu (2011) further explains that in saturated soil conditions, particularly on slopes or behind retaining walls, the potential for slope failure increases due to the combined effects of reduced shear strength and additional loads from water. This explains why landslides often occur after heavy rainfall and may lead to retaining wall failures, as observed on the Lampa–Timbong Road section. The combination of these factors frequently causes cracking, deformation, or collapse of retaining walls, along with soil mass movement that damages the road surface.

In addition, the local geological conditions, which tend to be unstable, coupled with high rainfall intensity and ineffective drainage systems, accelerate the softening process of the soil. Water retained within the soil decreases its bearing capacity and increases the likelihood of both horizontal and vertical ground movement. This further damages road infrastructure and poses significant safety risks to road users.

Figure 1. Damage Conditions at the Study Location

The road currently exhibits severe damage, as evidenced by the subsidence of the pavement. This phenomenon indicates soil instability that requires further investigation. In this case, the accumulation of subsurface water likely contributes to increased lateral pressure on the retaining wall, triggering significant structural deformation. The impacts are not only evident in physical structural damage, such as cracks and displacement in the retaining wall, but also in the deterioration of the road surface.

Therefore, a study entitled "The Influence of Groundwater Table on the Stability of Retaining Walls and Ground Movement on the Lampa–Timbong Road Section, Banggai District, Banggai Laut Regency" is deemed necessary. This technical study aims to analyze the relationship between groundwater table fluctuations and the stability of retaining structures along this road. Such an investigation will not only help identify the causes of existing damage but also serve as a foundation for planning rehabilitation measures that are more resilient to local hydrogeological conditions..

1.1 Embankment Slopes

Embankment slopes are commonly used for roadways, railways, and earth dams. The technical characteristics of embankment slopes are influenced by soil type, construction methods, and the degree of soil compaction. The utilization of local materials in road construction is one of the efficiency strategies that not only reduces transportation and production costs but also provides positive economic impacts for local communities. One of the potential local materials in Central Sulawesi is Domato, a type of limestone abundantly available in the Banggai Islands.

According to Milka (2023) in the Journal of Science and Technology Tadulako (9(2), 66–79), the use of Domato as a mixture for road pavement layers with an ideal proportion of 30% meets the standard gradation requirements of Bina Marga. The California Bearing Ratio (CBR) test results showed a value of 94%, which exceeds the minimum requirements for Class A subbase layers. This demonstrates that Domato possesses adequate technical quality in addition to its economic advantages.

Therefore, the utilization of Domato as a local material in road pavement works in Central Sulawesi can reduce the demand for crushed stone sourced from outside the island, thereby lowering unit reconstruction costs for roads in Banggai Islands Regency. Considering the abundant availability of this material, the use of Domato can also provide financial benefits for local residents.

1.2 Rainfall

According to Naryanto (2018), similar to other regions in Indonesia with a tropical climate, the climatic conditions in Banggai Laut Regency are generally influenced by the monsoon winds that occur from July to September. The dry season lasts until September, while the rainy season occurs from September to November. In general, the air temperature ranges between 28.2–31.2 °C. In addition, as a tropical and archipelagic area, Banggai Laut Regency has a relatively high humidity level, with a monthly average ranging from 65% to 78%. Meanwhile, the average air pressure recorded at the Bubung Luwuk Meteorological Station from January to December is between 1006.7 and 1012.4 mb, with an average wind speed of 4–7 knots. Banggai Laut Regency has a tropical and humid climate, with rainfall variations between 33 and 177.7 mm.

1.3 Groundwater Table

The groundwater table fluctuates seasonally and generally follows a sinusoidal curve, with both peak highs and low points. The design groundwater table is defined as the highest groundwater level; therefore, it is important to consider the timing of the soil investigation to avoid obtaining misleading data. As a reference, the seasonal fluctuation of the groundwater table between the highest and lowest levels in South Jakarta reaches approximately 5 meters. Ideally, to determine the design groundwater table, groundwater level observations should be carried out over one complete cycle of the wet and dry seasons. If such data are not available, groundwater surveys from surrounding wells at the project site should be conducted. This approach applies to areas that are not prone to flooding. If the project site is frequently flooded, the design groundwater table must be assumed at the same level as the road surface.

1.4 Soil Classification System

Several versions of soil classification systems exist due to the wide variability in soil properties. Some of the commonly used soil classification methods include:

- AASHTO Soil Classification System
- Unified Soil Classification System (USCS)

Table 1. Soil Classification from CPT (Cone Penetration Test)

Qc	fs	Classification
6.0	0.15 – 0.40	Humus, very soft clay
6.0 – 10.0	0.20	Loose silty sand, very loose sand
	0.20 – 0.60	Soft clay, soft silty clay
10.0 – 30.0	0.10	Loose gravel
	0.10 – 0.40	Loose sand
	0.40 – 0.80	Clay or silty clay
	0.80 – 2.00	Slightly stiff clay
30 – 60	1.50	Silty sand, slightly dense sand
	1.0 – 3.0	Stiff clay or silty clay
60 – 150	1.0	Loose sandy gravel
	1.0 – 3.0	Dense sand, silty sand, stiff clay or stiff silty clay
	3.0	Stiff clayey gravel
150 – 300	1.0 – 2.0	Dense sand, gravelly sand, coarse sand, very dense silty sand

Source: Das, 1995

1.5 Design of Retaining Wall

Retaining walls (DPT) function to resist soil movement that could potentially affect the stability and safety of a structure. At the project site, a cantilever-type retaining wall is used, which is commonly applied due to its ease of construction and cost efficiency (Wijaya et al., 2024). According to Chantika and Agustina (2021), a cantilever retaining wall is a reinforced concrete structure designed to withstand lateral earth pressure. The advantages of this type of wall include high efficiency, ease of implementation, and good stability.

According to Das (2016), in designing a retaining wall, a designer must assume certain dimensions. These assumptions, referred to as proportions, allow the designer to check the trial section of the wall for stability. If the stability check yields unsatisfactory results, the section can be modified and re-examined. The figure below illustrates the general proportions of various components of a retaining wall that may be used for preliminary checks.

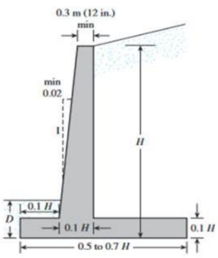


Figure 2. Estimated Dimensions of the Retaining Wall for Cantilever Wall Stability Analysis Source: Das, 2016

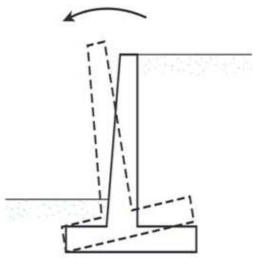


Figure 3. Stability Against Overturning Source: Das, 2016

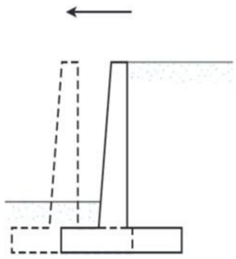


Figure 4. Stability Against Sliding

Source: Das, 2016

$$F_{gl} = \frac{\Sigma M_R}{\Sigma M_O}$$

$$F_{gs} = \frac{\Sigma F_{R'}}{\Sigma F_d} \geq 1{,}5$$

$$FS_{\text{Bearing Capacity}} = \frac{q_u}{q_{max}}$$

According to the Indonesian National Standard for Geotechnical Design (SNI, 2017), every retaining wall must be evaluated for its stability against overturning, lateral sliding, and bearing capacity failure. The required minimum factors of safety are specified as follows:

a) Overturning stability: not less than 2.0;
b) Lateral sliding stability: not less than 1.5;
c) Bearing capacity stability: not less than 3.0;
d) Global stability: not less than 1.5;
e) Seismic stability: not less than 1.1.

II. METHODOLOGY

The data collection techniques in this research employed observation, literature study, document review, and testing, which were conducted to obtain factual information from existing phenomena and to gather relevant evidence regarding the Effect of Groundwater Table on Retaining Wall Stability and Soil Movement along the Lampa–Timbong Road Section, Banggai District, Banggai Laut Regency. For this purpose, both primary and secondary data were required.

1. Primary Data

Primary data were obtained from direct observations at the research site, including:

- **Site inspection**, which aimed to observe the conditions of the study location. A failure plane of approximately 1.70 meters behind the wall was identified, indicating the potential for soil mass displacement. The main issue observed in the field was the potential for lateral movement of the retaining wall.
- **Soil sampling**, conducted to determine the physical and mechanical parameters of the soil, which were then tested in the laboratory. The laboratory tests included sieve analysis, soil unit weight, cohesion, angle of internal friction, permeability, and others. Soil samples were taken from the area behind the retaining wall using a pipe at a sampling depth of 50 cm.

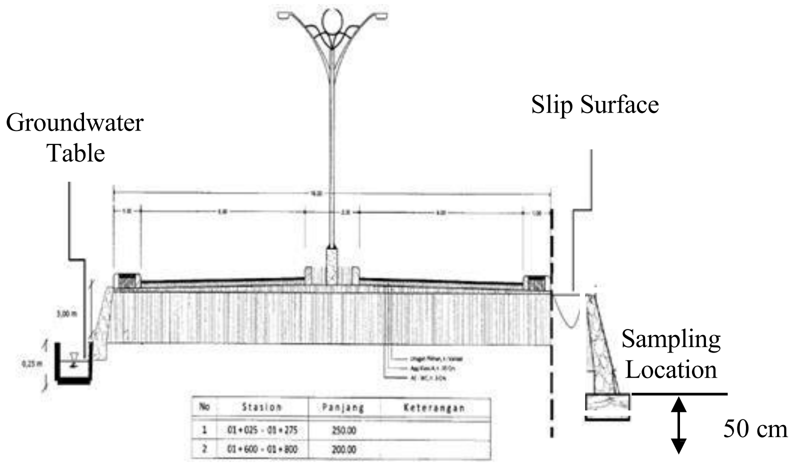


Figure 6. Soil Sampling Point

2. Secondary Data

The secondary data in this study on the Lampa–Timbong road section include:

- **Retaining Wall Dimensions**

The retaining wall at this location has a height of approximately 5 meters. Its primary function is to resist the lateral earth pressure of the backfill soil with a height of about 5 meters on the right side of the road, as well as to provide stability for the pavement with a width of 6 meters.

- **In-Situ Soil Test Data**

This refers to the results of the Cone Penetrometer Test (CPT).

Table 2. Layers Based on qc – Simple Interpretation of Soil Profile

Depth (m)	qc Value (kg/cm²)	Layer Interpretation	Characteristics
0 – 2	0	Very soft, possibly humus or water-saturated organic soil	Very weak zone, high risk
2.2 – 4	23 – 40	Stiff clay / silt	Strength of soil begins to increase
4.2 – 5.2	> 40	Dense sand or stiff silt	Relatively strong layer, supports stability
5.2	120	Hard to very hard layer	Soil strength increases drastically; very suitable for pile foundation at this depth

Notes:

- Total depth: 5.20 m
- Critical zone: 0 – 2 m (very soft layer)
- Implication: Groundwater in the weak zone increases the risk of reduced retaining wall stability and potential slope failure.
-

- **Rainfall intensity**

Table 3. Monthly Rainfall Data

Monthly Rainfall Data (mm/Month)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	38.00	102.70	193.30	98.80	188.40	127.90	143.20	119.80	53.50	95.50	83.70	220.40
2016	105.50	72.00	139.00	65.80	26.00	241.80	148.20	6.40	32.10	39.50	35.30	240.40
2017	39.70	64.60	153.00	196.40	149.10	148.50	235.40	137.80	32.10	19.60	73.70	109.50
2018	34.20	80.20	61.60	103.20	100.20	120.10	178.50	71.60	58.70	53.90	61.60	102.30
2019	231.70	80.90	139.10	164.10	73.60	123.60	58.20	48.70	68.40	73.10	63.70	154.50
2020	55.20	3.40	96.00	119.60	200.90	145.00	115.20	182.60	87.70	65.30	294.80	32.90

2021	121.80	36.40	62.50	148.90	114.00	150.30	228.50	59.40	122.50	22.70	65.90	120.80
2022	126.30	130.40	203.20	123.40	129.60	102.40	301.40	113.60	36.00	44.00	61.20	21.00
2023	74.80	130.30	170.50	197.60	182.80	163.20	465.80	331.90	114.00	39.60	136.20	109.20
2024	114.10	54.70	179.80	145.40	56.60	566.70	42.40	69.00	38.30	20.00	20.10	116.70

Source: Meteorology, Climatology, and Geophysics Agency (BMKG) of Banggai Laut

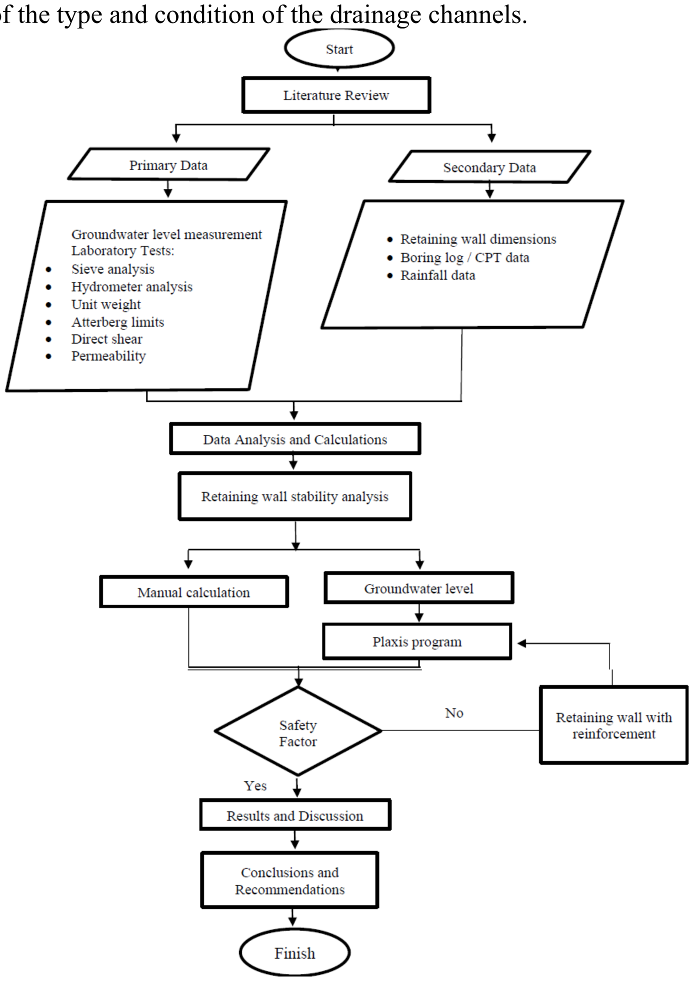
Table 4. Annual Maximum Rainfall Data

No	Year	Annual Maximum Rainfall (mm)
1	2015	220.40
2	2016	241.80
3	2017	235.40
4	2018	178.50
5	2019	231.70
6	2020	284.90
7	2021	264.10
8	2022	301.40
9	2023	465.80
10	2024	566.70

Source: Meteorology, Climatology, and Geophysics Agency (BMKG) of Banggai Laut

- **Groundwater Table Measurement at the Research Site**

The groundwater table was measured at a depth of 0.35 meters from the ground surface behind the retaining wall. The measurement was obtained through a topographic survey, observation of the existing groundwater table, and identification of the type and condition of the drainage channels.



Groundwater level measurement Laboratory Tests:
- Sieve analysis
- Hydrometer analysis
- Unit weight
- Atterberg limits
- Direct shear
- Permeability
- Retaining wall dimensions
- Boring log / CPT data
- Rainfall data

III.RESULTS AND DISCUSSIO

1. General Overview of the Research Location

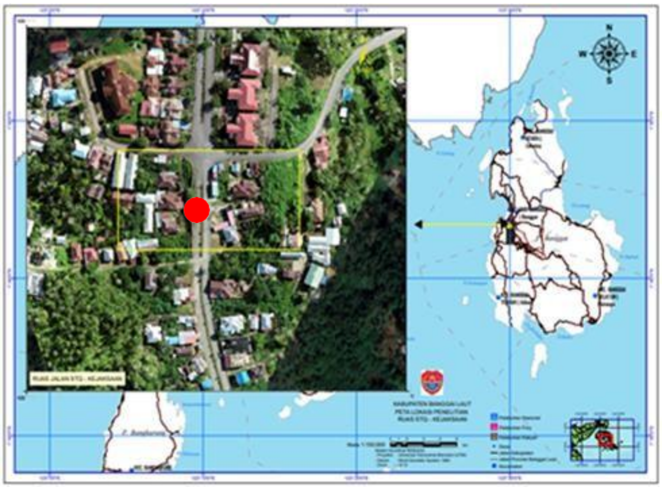


Figure 7. Research Location

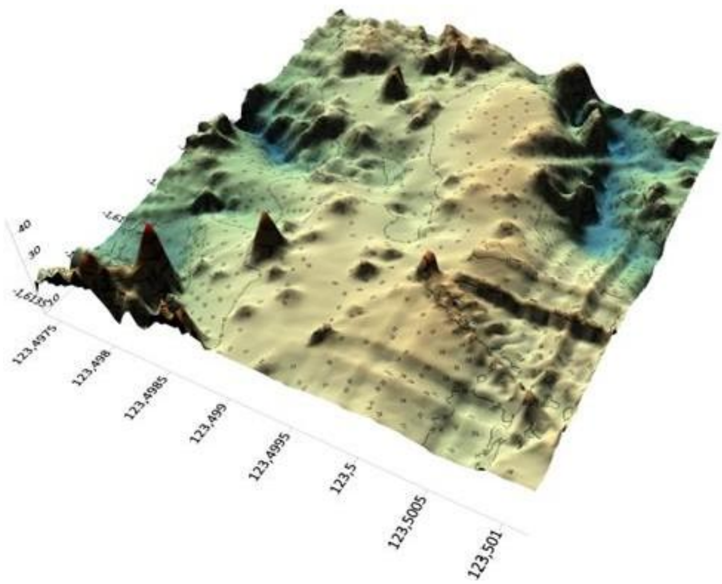


Figure 8. Contour Map of the Research Location

Banggai Kepulauan Regency is one of the regions in Central Sulawesi Province with a land area of approximately 2,448.79 km² and consisting of 121 islands, five of which are medium-sized, while the rest are small to very small, including coral rocks that rise above the sea surface. The region is surrounded by Tomini Bay to the north, Tolo Bay to the south, Peling Strait to the west, and the Maluku Sea to the east. Its geographical condition as an archipelago causes the availability of construction materials, particularly aggregates for road pavement works, to be highly dependent on the utilization of local resources (Milka, 2023). The research site is located along the Lampa–Timbong Road section, Banggai Laut Regency, Central Sulawesi Province. Geographically, the research site is situated on an embankment along the Lampa–Timbong Road section, Banggai Laut Regency, at the coordinates 1°37'43.5"S 123°30'04.5"E.

2. Analysis of Soil and Rock Characteristics on the Lampa–Timbong Road Section, Banggai Laut Regency, Central Sulawesi Province

Table 5. Geotechnical Characteristics of the Lampa–Timbong Road, Banggai Laut, Central Sulawesi

No	Description	Symbol	Unit	East	West
1	Water Content	W	%	47.79	43.75
2	Specific Gravity	Gs	-	2.67	2.66
3	Bulk Density (Wet)	γb	gr/cm³	1.37	1.45
4	Dry Density	γd	gr/cm³	0.92	1.01
5	Atterberg Limits				
	a. Liquid Limit	LL	%	57.11	57.39
	b. Plastic Limit	PL	%	41.59	41.29
	c. Plasticity Index	PI	%	15.51	16.10
6	Sieve Analysis				
	a. Gravel	G	%	0.00	0.00
	b. Sand	S	%	23.63	22.88
	c. Silt/Clay	M/C	%	76.37	77.12
	d. Coefficient of Uniformity	Cu	-	3.58	26.00
	e. Coefficient of Gradation	Cc	-	1.38	1.58
7	Hydrometer Analysis				
	a. Silt	M	%	67.99	69.34
	b. Clay	C	%	8.37	7.78
8	Direct Shear Test				
	a. Cohesion	c	kg/cm²	0.041	0.074
	b. Friction Angle	φ	°	17.19	15.77
9	Permeability	k	cm/s	0.001	0.001
10	Soil Classification Symbol				
	AASHTO			A-4	A-4
	USCS			MH	MH

The results of laboratory testing of the physical and mechanical properties of the soil indicate that the specific gravity values range between 2.65 – 2.70. According to Das (2002), the soil can be classified as silt. Based on the laboratory test results, the soil on the eastern and western sides of the road is categorized as high-plasticity silt. According to the AASHTO classification, the soil belongs to group A-4, while under the USCS classification, it falls within group MH (Inorganic Silt of High Plasticity). The characteristics of this soil show high water content, low dry unit weight, as well as relatively high liquid limit and plasticity index values. In addition, the test results indicate that the fraction passing through the No. 200 sieve exceeds 75%, indicating the dominance of fine particles. With a very low permeability value ($k = 0.001$ cm/s), the soil has poor drainage capacity, making it prone to saturation and increased pore water pressure. Such conditions may lead to settlement, low bearing capacity, and poor stability if the soil is used directly for construction without special treatment.

Based on the results of the physical property tests from two sampling points located at the eastern and western sections of the road the USCS classification system indicates that both belong to the fine-grained soil group. This conclusion is based on sieve analysis results, which show that the percentage of particles passing through the No. 200 sieve reaches 76.37% for the upper point and 77.12% for the lower point, meaning that more than 50% of the material consists of fine particles. According to the USCS classification system, soils with more than 50% passing the No. 200 sieve cannot be categorized as sands (SP or SW), but are instead grouped as fine- grained soils.

Furthermore, based on the results of the Atterberg limit tests, the soil at both points has a liquid limit (LL) value greater than 50% and a plasticity index (PI) that falls below the A-line, which means the soil can be classified as inorganic silt of high plasticity, denoted by the symbol MH in the USCS system. Therefore, even though the laboratory data also included the coefficient of uniformity (Cu) and coefficient of gradation (Cc), these values were not used in the classification process because they are only relevant for coarse-grained soils such as sands and gravels.

3. Retaining Wall Analysis (Manual Calculation)

Table 6. Verification of Retaining Wall Calculation Results

No	Examination	Result Value	Design Requirement	Remark
1	Sliding	8.09	≥ 1.5	Satisfied
2	Overturning	6.92	≥ 2.0	Satisfied
3	Soil Bearing Capacity	2.70	≥ 2.0	Satisfied

4. Geotechnical Modeling Analysis in Plaxis 2D

Table 7. Subsurface Soil Stratigraphy of the Study Area

Description	Unit	Natural Soil (Silt)	Loose Sand	Dense Sand
ɣb (Bulk Unit Weight)	kN/m³	13.78	16.00	18.00
ɣsat (Saturated Unit Weight)	kN/m³	9.46	13.00	15.00
Cohesion	kN/m²	5.64	147.10	196.13
Friction Angle	°	16.50	33.00	37.00
Permeability	m/day	0.86	0.86	–
Elastic Modulus	kN/m²	10,000	120,000	150,000
Poisson's Ratio	–	0.45	0.30	0.33

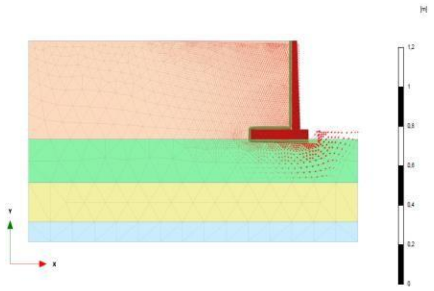


Figure 9. Direction of Displacement on DPT Groundwater Table at -0,35 m

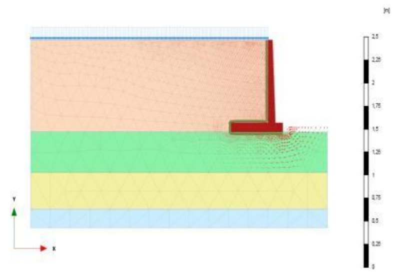


Figure 10. Direction of Displacement on DPT + Groundwater Table at 1 m

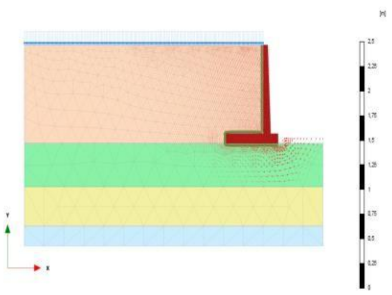


Figure 11. Direction of Displacement on DPT + Groundwater Table at 2 m

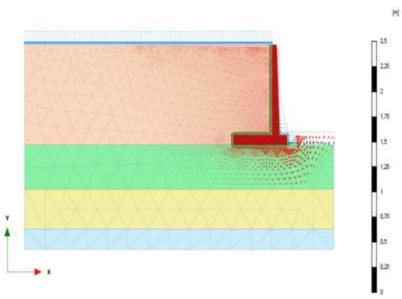


Figure 12. Direction of Displacement on DPT + Groundwater Table at 3 m

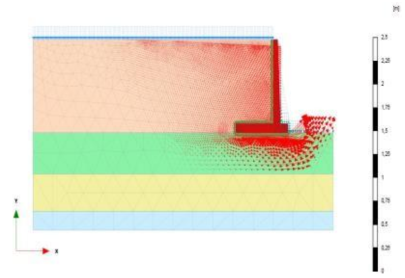
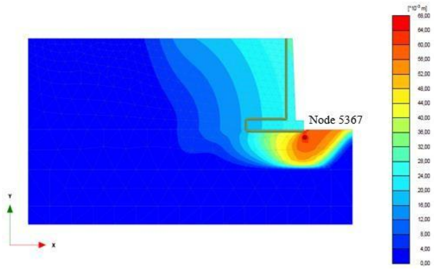


Figure 13. Direction of Displacement on DPT + Groundwater Table at 4 m



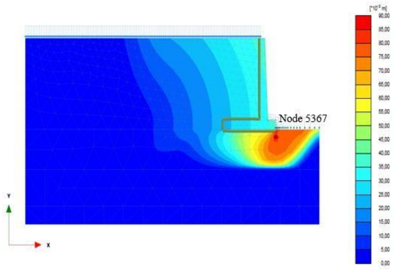
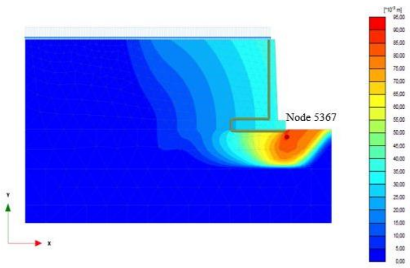


Figure 14. Slip Surface in the Direction of Displacement Displacement on DPT + Groundwater Table at -0.35 m

Figure 15. Slip Surface in the Direction of on DPT + Groundwater Table at 1 m



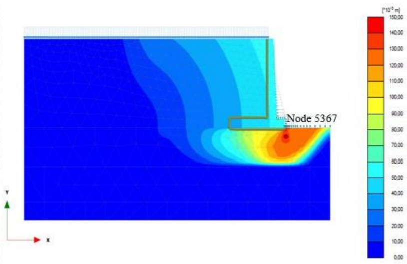


Figure 16. Slip Surface in the Direction of Displacement Displacement on DPT + Groundwater Table at 2 m

Figure 17. Slip Surface in the Direction of on DPT + Groundwater Table at 3 m

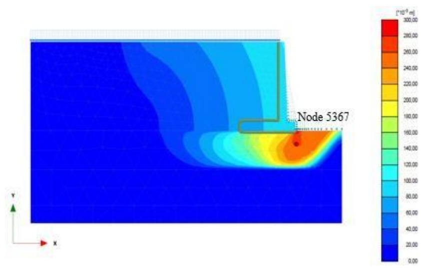
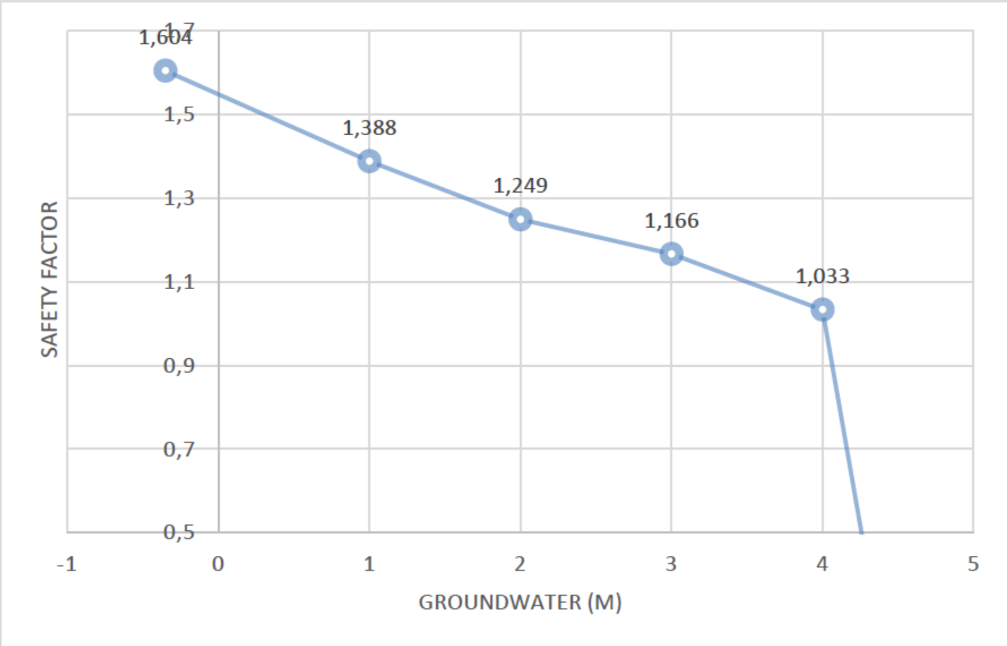


Figure 18. Slip Surface in the Direction of Displacement on DPT + Groundwater Table at 4 m



Grafik 1. Graph of the Relationship between Safety Factor and Groundwater Table Position

Table 8. Stability of Retaining Wall (DPT) with Variation of Groundwater Level

Condition	Groundwater Depth (m)	Safety Factor of DPT	Maximum Displacement Node 5367 (m)
1	–0.35	1.604	0.0656
2	+1.00	1.388	0.0875
3	+2.00	1.249	0.0933
4	+3.00	1.166	0.1461
5	+4.00	1.033	0.2931
6	+4.50	Collapse	–

Notes:

- Rainfall intensity = 0.01889 m/day
- Condition 1 = Retaining wall + Groundwater level –0.35 m
- Condition 2 = Retaining wall + Rainfall 0.01889 m/day + Groundwater level +1 m
- Condition 3 = Retaining wall + Rainfall 0.01889 m/day + Groundwater level +2 m
- Condition 4 = Retaining wall + Rainfall 0.01889 m/day + Groundwater level +3 m
- Condition 5 = Retaining wall + Rainfall 0.01889 m/day + Groundwater level +4 m
- Condition 6 = Retaining wall + Rainfall 0.01889 m/day + Groundwater level +4.5 m

The analysis results indicate that groundwater table fluctuations have a significant impact on the stability performance of the retaining wall reinforcement system (DPT). Under the initial condition with the groundwater table at -0.35 m, a safety factor of 1.604 was obtained with a total displacement of 0.0656 m, which still indicates a stable condition. However, as rainfall infiltration with an intensity of 0.01889 m/day occurs, the groundwater table rises, leading to an increase in pore water pressure. The rise of the groundwater table to +1.00 m up to +3.00 m results in a decrease in the safety factor from 1.388 to 1.166, accompanied by an increase in deformation from 0.0875 m to 0.1461 m. A critical condition is reached at the groundwater table elevation of +4.00 m with a safety factor of 1.033 and displacement of 0.2931 m, while at +4.50 m the system experiences total failure. In general, the rise of the groundwater table due to rainfall accumulation generates an increase in hydrostatic pressure and a reduction in soil effective stress, which progressively amplifies the active lateral forces and accelerates structural deformation until it exceeds the retaining wall's capacity.

IV.CONCLUSION

Based on the geotechnical study of the Lampa–Timbong road section in Banggai Laut Regency, it can be concluded that the soil at the site is fine-grained, classified as MH (Inorganic Silt of High Plasticity) according to the USCS and A-4 (silty soil) according to the AASHTO system. This indicates high plasticity, very low permeability, high natural moisture content, and low bearing capacity. Under the initial condition (–0.35 m), the safety factor was 1.604 with a displacement of 0.0656 m, indicating a stable condition. However, as the groundwater level rose to +4.0 m, the safety factor decreased to 1.033 and the displacement increased to 0.2931 m. The most critical condition occurred when the groundwater level reached +4.50 m, resulting in total failure of the reinforcement system. Therefore, it can be concluded that the stability of the retaining wall (DPT) is highly sensitive to groundwater level fluctuations, with the safe limit occurring when the groundwater level is around +4.0 m.

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