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DESIGN OF RETAINING WALLS FOR LANDSLIDE MITIGATION ON THE BULONTIO—TOLINGGULA ROAD SEGMENT, NORTH GORONTALO REGENCY, GORONTALO PROVINCE

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ABSTRACT

The Bulontio—Tolinggula Road section, located in North Gorontalo Regency, was experiencing landslide issues caused by low soil bearing capacity. An analysis of the existing slope conditions indicates a factor of safety that signifies instability. To address this issue, a technical solution is required through the design of a retaining wall. Calculations are carried out using Rankine's theory for normal earth pressure conditions and the Mononobe-Okabe theory for seismic conditions. The analysis results show that a gravity wall requires larger dimensions compared to a cantilever wall to achieve the same level of stability. Furthermore, the use of pile strengthening significantly increases the factor of safety, especially under seismic conditions. Segmental pile strengthening also proves to be effective and economical, enhancing stability without compromising structural safety. After implementing the retaining wall and pile strengthening, safety factors (SF) were achieved for sliding, overturning, bearing capacity, and global stability. These analysis and design results provide a solution to overcome landslide problems in disaster-prone areas and support the development of safe and sustainable transportation infrastructure.

Keywords: Landslide, Retaining Wall, Pile, Stability, Safety Factor

1. INTRODUCTION

The development of transportation infrastructure in Indonesia continues to increase. One of the main challenges in road construction within hilly topographical areas is the risk of landslides. Landslides can occur due to a combination of unstable geological conditions, excessive loading, and weak soil characteristics. Their impacts may disrupt accessibility, damage infrastructure, and pose safety hazards.

The Province of Gorontalo, particularly North Gorontalo Regency, has geological characteristics that are highly susceptible to landslides. According to data from BNPB (2023), this region is classified as having a high risk of landslide disasters. The Bulontio—Tolinggula road segment has experienced landslides due to low soil bearing capacity in the area. One of the technical solutions to address landslides is the construction of retaining walls. The selection and design of retaining wall types must take into account

local geotechnical conditions, acting forces, as well as safety and efficiency considerations.

This design aims to analyse the soil characteristics and causes of landslides along the Bulontio—Tolinggula road segment, and to design two types of retaining walls: gravity-type and cantilever-type. Furthermore, a comparison of the safety factors of both types is conducted to determine the most optimal solution for landslide mitigation.

2. THEORITICAL STUDY

Landslides

Sebayang et al. (2022) stated that landslides, also referred to as mass movements, are movements of soil or rock that shift downward or away from their original position. Slope failures can occur when the gravitational component becomes so significant that it exceeds the shear resistance that the soil can mobilize along the failure plane (Hardiyatmo, 2003).

Retaining Walls

Retaining walls are construction structures designed to hold back soil that has a slope or inclination, where the soil's natural stability is insufficient to support itself. This relates to soil stability where, to maintain stability and prevent landslides, particularly in sloped areas, retaining walls may be constructed. The function of a retaining wall is to resist the lateral pressure exerted by the retained soil behind it due to loads from above or other external forces (Suhudi & Rahma, 2022).

Lateral Earth Pressure

The force exerted by soil behind a retaining structure generates what is known as lateral earth pressure. The magnitude of this pressure is highly influenced by the displacement of the retaining wall and the inherent properties of the soil (Hardiyatmo, 2003).

Stability of Retaining Walls

Stability analysis of retaining walls must meet four criteria: safety against sliding and overturning, foundation bearing pressure must be less than the allowable bearing capacity of the soil, and overall structural stability must be ensured (Hardiyatmo, 2011).

Seismic Requirements for Retaining Walls

According to SNI 8460:2017, the evaluation of seismic forces on retaining walls must be conducted using an appropriate approach that adheres to the specified conditions and limitations. One such method is the pseudostatic approach, which incorporates the Mononobe (1929) and Okabe (1926) methods.

3. METHOD

The retaining wall design is located at the landslide site along the Bulontio—Tolinggula road segment in North Gorontalo Regency, Gorontalo Province. The data used for the analysis include SPT results and topographic data of the landslide area. These data were analyzed to interpret the soil profile and stratigraphy. An analysis of the existing conditions was carried out using Geostudio software. Landslide mitigation was addressed through the analysis and design of two types of retaining walls: cantilever and gravity. Earth pressure was calculated using Rankine's theory, while seismic conditions were evaluated using the Mononobe-Okabe method. The retaining wall design was further reinforced with pile foundations, and its stability and safety were assessed based on SNI 8460:2017. SAP2000 software was used to obtain the internal forces of the cantilever retaining wall, which were then used in the reinforcement design. The final outcome of the design includes detail engineering design and a comparative analysis between the gravity and cantilever retaining wall systems.

4. RESULT AND DISCUSSION

Soil Data Interpretation

The SPT borehole drilling log data from borehole 02 is used for design purposes, as it is the closest to the planned retaining wall location. The N-SPT values obtained are then correlated in Table 1 with parameters such as unit weight, cohesion, and internal friction angle using empirical correlation tables from the literature (Kurniawan & Hadimuljono, 2020).

Table 1 Soil Parameters

Depth (m)	N-SPT (Average)	γ (kN/m^3)	c (kN/m^2)	Ø (°)
0 – 3	2,667	15	0	14
3 – 10	18,8	16,5	0	24
10 – 15	53,333	20,4	0	30
Backfill	-	18	0	20

Existing Condition Analysis

According to SNI 8460:2017, the required factor of safety for slopes is 1.5. This indicates that the factor of safety (SF) for the existing condition, as analyzed using Geostudio software and shown in Figure 1, needs to be improved by providing strengthening in order to increase the safety factor to a stable and safe condition.

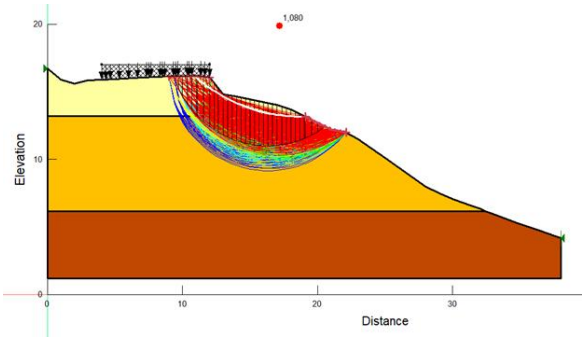

Figure 1 Existing condition with initial safety factor (SF) = 1.080

Analysis of Lateral Earth Pressure

$$Ka = \text{TAN}\left(45 - \left(\frac{\phi}{2}\right)\right)^2$$

$$\text{Kae} = \frac{\cos(\phi - \Theta - \beta)^2}{\cos(\Theta)^2.\cos(\beta).\cos(\delta + \Theta + \beta)\left\{1 + \sqrt{\frac{\sin(\delta + \phi).\sin(\phi - \alpha - \beta)}{\cos(\delta + \Theta + \beta).\cos(\Theta - \alpha)}}\right\}^2}$$

Table 2 Summary of lateral earth pressure coefficients

Lateral Pressure	Backfill	1st Layer	2nd Layer
Ka	0,490	0,610	0,422
Kae	0,734	1,004	0,653

Design of Cantilever Retaining Wall

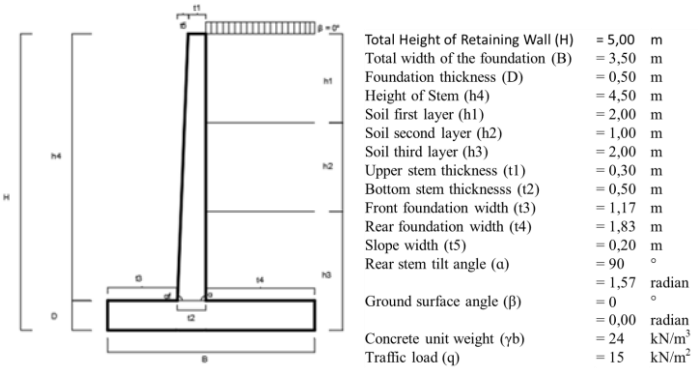

Figure 2 Detailed dimensions of cantilever wall

a. Sliding Stability

Weight of Cantilever (ΣW) = 251,575 kN

Fd total (static + dynamic) = ΣPae + ΣPs = 155,807 + 137,653 = 293,461 kN

Overturning moment of Pa static (Ms) = 277,009 kN.m

FS (sliding) $= \frac{\Sigma W.\tan\delta b}{\Sigma Fd\ total} = 0{,}382 < 1{,}5$ (Not safe)

b. Overturning Stability

Total of overturning moment (Mo) = ΣMae + ΣMs = 317,658 + 277,009 = 594,667 kN

Resisting moment (Mr) = 566,482 kN

FS (overturning) $= \frac{\Sigma Mr}{\Sigma Mo} = 0{,}953 < 1{,}5$ (Not safe)

c. Eccentricity

Xe $= \frac{\Sigma Mw - \Sigma Mo}{\Sigma W} = -0{,}112\ m$

e $= \frac{B}{2} - Xe = 1{,}862\ m$

Check eccentricity (e) against B/6 = 1,862 m > 0,583 m (Not ok, need piles)

Cantilever Retaining Wall with A Pile

Pile with a diameter of 0.8 m and a length of 5 m is used.

a. Sliding Stability

H $= \frac{y0 \times L^2 \times nh}{2} = \frac{0{,}01 \times 5^2 \times 7000}{2} = 875$ kN/m

Fr initial = 112,008 kN

Fr total = Fr initial + pile = 987,008 kN

Fd total = 293,461 kN

FS (sliding) $= \frac{Fr\ total}{Fd\ total} = 3{,}363$ (Satisfactory)

b. Overturning Stability

The calculation of Mmax is based on the moment occurring at the pile head of fixed-head (Hardiyatmo, 2011).

Kp $= \text{TAN}\left(45 + \left(\frac{24}{2}\right)\right)^2 = 2{,}371$

Mmax $= \gamma \times d \times L^3 \times Kp = 16{,}5 \times 0{,}8 \times 5^3 \times 2{,}371 = 3912{,}454$ kN

Pile moment resistence $= \frac{Mmax}{SF} = 1304{,}151$ kN

Overturning moment (Mo) = 594,667 kN

Resisting moment (Mr) = 566,482 kN

Mr total = Mr + pile moment resistance = 1870,633 kN

$$\text{FS(overturning)} = \frac{\Sigma \text{Mr total}}{\Sigma \text{Mo}} = \frac{1870,633}{594,667} = 3,146$$ (Satisfactory)

c. Bearing Capacity

Qb = C × N × Ab = 4476,770 kN

Qf = f × as = 549,150 kN

Qall $= \frac{Qb+Qf}{3} = 1675,307\ kN$

Pile weight = 60,319 kN

Net load = Qall – pile weight > Retaining wall load

= 1614,988 kN > 251,575 kN (Satisfactory)

Global Stability of Cantilever Retaining Wall with Pile Strengthening

The results of the global stability analysis of the cantilever retaining wall with pile strengthening show a safety factor (SF) value of 4.306 (safe), as illustrated in Figure 3.

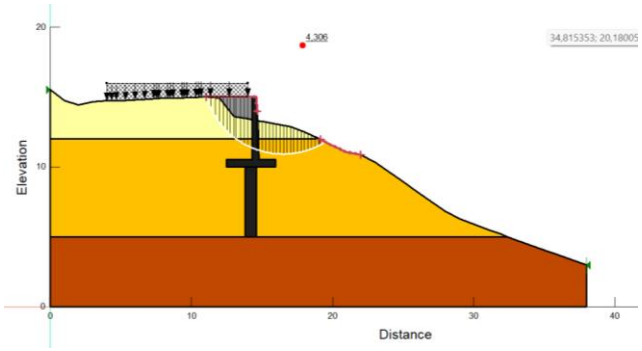

Figure 3 Global stability of cantilever retaining wall with pile

Cantilever Retaining Wall with Pile Strengthening per Segment

The analysis of the cantilever retaining wall was carried out using calculations based on three piles per 6-meter segment along the longitudinal direction, as shown in Figure 4. It was found that the pile strengthening per segment is both effective and economical without compromising the structural safety, especially under seismic conditions.

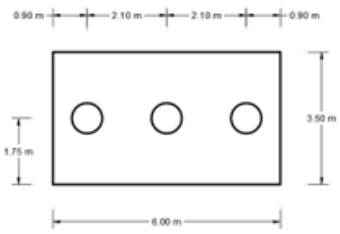

Figure 4 Piles configuration per segment

Reinforcement of Cantilever Retaining Wall

Modeling of the retaining wall was carried out using SAP2000 as shown in Figure 5 to obtain internal forces. The modeling was performed on a single 6-meter longitudinal segment for reinforcement calculations, which are presented in the detail engineering design in Figure 6.

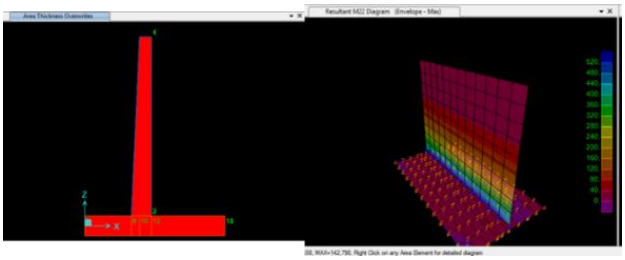

Figure 5 Internal force analysis of cantilever wall

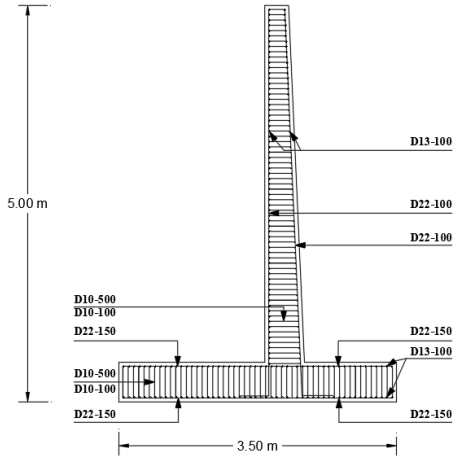

Figure 6 Reinforcement of cantilever wall

Design of Gravity Retaining Wall

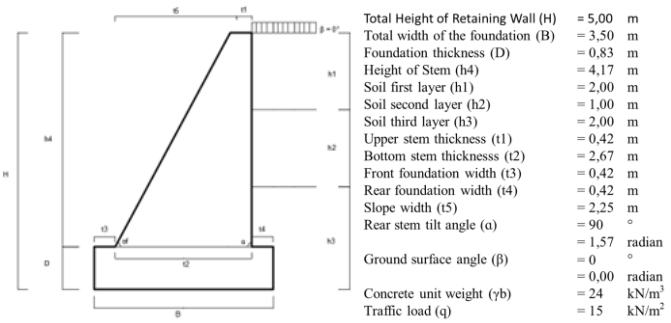

Figure 7 Detailed dimensions of gravity wall

a. Sliding Stability

Weight of Gravity (ΣW) = 259,688 kN

FS (sliding) $= \frac{\Sigma W.\tan\delta b}{\Sigma Fd\ total} = \frac{115,620}{293,461} = 0,394 < 1,5$ (Not safe)

b. Overturning Stability

Resisting moment (Mr) = 574,839 kN

FS (overturning) $= \frac{\Sigma Mr}{\Sigma Mo\ total} = 0,967 < 1,5$ (Not safe)

c. Eccentricity

Xe $= \frac{\Sigma Mr - \Sigma Mo}{\Sigma W} = \frac{574,839 - 594,667}{259,688} = -0,076\ m$

e $= \frac{B}{2} - Xe = 1,826\ m$

Check eccentricity (e) against B/6 = 1,826 m > 0,583 m (Not ok, need piles)

Gravity Retaining Wall with A Pile

Pile with a diameter of 0.8 m and a length of 5 m is used.

a. Sliding Stability

Fr initial = 115,620 kN

Fr total = Fr initial + pile = 990,620 kN

FS (sliding) $= \frac{Fr\ total}{Fd\ total} = 3,376$ (Satisfactory)

b. Overturning Stability

Resisting moment (Mr) = 574,839 kN

Mr total = Mr + pile moment resistence = 1878,991 kN

FS (overturning) $= \frac{\Sigma Mr\ total}{\Sigma Mo} = \frac{1878,991}{594,667} = 3,160$ (Satisfactory)

c. Bearing Capacity

Net load = Qall – pile weight > Retaining wall load

= 1614,988 kN > 259,688 kN (Satisfactory)

Global Stability of Gravity Retaining Wall with Pile Strengthening

The results of the global stability analysis of the gravity retaining wall with pile strengthening show a safety factor (SF) value of 4.197 (safe), as illustrated in Figure 8.

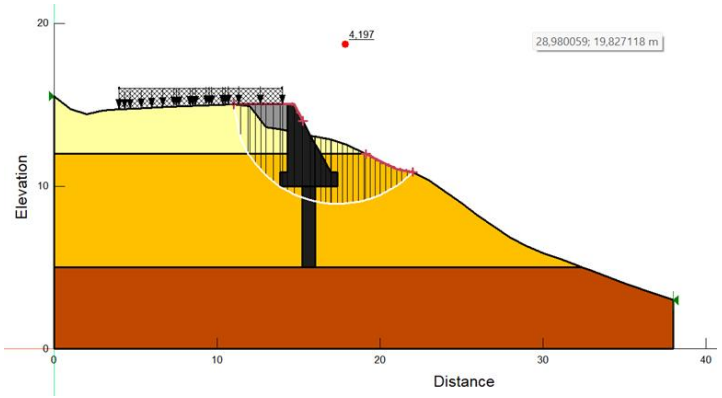

Figure 8 Global stability of gravity retaining wall with pile

Gravity Retaining Wall with Pile Strengthening per Segment

The analysis of the gravity retaining wall was carried out using calculations based on three piles per 6-meter segment along the longitudinal direction, as shown in Figure 4, using the same pile configuration as the cantilever wall. It was found that pile strengthening per segment is also effective and economical without compromising structural safety, especially under seismic conditions.

5. CONCLUSION

The soil characteristics at the design site exhibit significant variability with depth. The upper soil layer is classified as very weak, as indicated by low N-SPT values. Analysis of the existing conditions shows that the slope is unstable, prompting the design of both cantilever and gravity-type retaining walls.

Based on dimensional comparisons, the gravity-type retaining wall has a more massive structure, particularly in stem thickness, compared to the cantilever type, even though both designs share the same total height (H) of 5.00 meters and overall foundation width (B) of 3.50 meters. While the gravity wall is conceptually simpler, it requires significantly larger dimensions and material volume to achieve equivalent stability.

Under seismic conditions, the safety factors decrease significantly, leading to the addition of pile strengthening with a diameter of 80 cm and a length of 5 meters. Analysis of the retaining wall with pile strengthening shows that the piles significantly improve

stability against lateral forces, overturning moments, and bearing capacity under dynamic seismic loading conditions.

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