SOIL SLOPE REINFORCEMENT USING CANTILEVER RETAINING WALL ON THE WEST RING ROAD OF SADAWARNA DAM, SUBANG DISTRICT

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ABSTRACT

The research was conducted in the West Ring Road of Sadawarna Dam, Subang Regency. This research aims to provide recommendations for the design of cantilever retaining wall to increase the value of the slope safety factor in the research area. Calculation of the value of the slope safety factor uses the limit equilibrium method with the Janbu calculation method. In actual conditions, the value of the slope safety factor shows an unstable value referring to SNI 8460:2017, namely in static conditions with a vehicle load is 1.31 and in pseudo-static conditions with a vehicle load is 1.083. Slope strengthening was carried out using cantilever retaining wall. The retaining wall design that has been made meets the criteria for stability against overturning, stability against sliding, and stability for the bearing capacity of the soil. The safety factor value for slope with retaining wall shows a stable FS value referring to SNI 8460:2017, namely 1.53 in static conditions with vehicle loads and 1.11 in pseudo-static conditions with vehicle loads.

Keyword: slope, safety factor, retaining wall, cantilever

INTRODUCTION

The construction of the Sadawarna Dam in Subang Regency was followed by the construction of a dam ring road access which was previously cut off due to the dam construction project (Gunawan, 2023). The area around the Sadawarna Dam, especially Cijambe District, is a hilly area, so road access work at several points is carried out by cutting through hilly cliffs. On one of the West Ring Roads of the Sadawarna Dam in Cijambe District, an artificial slope was found due to the construction of a road project at the bottom and top of the slope. This condition requires an evaluation of slope stability studies due to the additional vehicle load at the top of the slope.

Slope stability is part of the criteria for regional development so proper slope stability analysis is needed to prevent failures such as slope collapse (Zakaria, 2010). Therefore, a strengthening method is needed to support slope stability, such as the construction of retaining wall. Retaining wall function to hold the soil behind the wall structure so that it can prevent soil collapse (Sahfitri et al., 2021).

This research aims to analyze slope reinforcement in the research area using cantilever retaining wall to obtain stable slope safety factor values. This aims to ensure that road construction projects at the foot and top of the slope are safe from landslides that could occur.

RESEARCH METHOD

The research began by calculating the value of the safety factor for the slope of the research area in several conditions including static conditions with vehicle loads and pseudo-static conditions with vehicle loads. If an unstable slope safety factor value is obtained, planning will then be carried out to strengthen the slope with a cantilever retaining wall. The slope safety factor is calculated based on the limit equilibrium method using the Janbu (1954) calculation method.

The Janbu method formulates the general equation of balance by solving vertically and parallel to the base of each slice. The safety factor equation of the Janbu Method is described as follows:

$$SF_{janbu} = fo.SF_a \quad ....(1)$$

$$fo = 1 + b1\left[\frac{d}{L} - 1{,}4\left(\frac{d}{L}\right)^2\right] \quad ....(2)$$

$$SF_a = \frac{\sum(c.b_n[W_n - u.b_n]tan\varphi)\frac{sec^2\alpha_n}{1+\frac{tan\varphi.tan\alpha_n}{F}}}{\sum W_n.\tan\alpha} \quad ....(3)$$

Information: SF_{janbu} = corrected Janbu Method safety factor value, fo = correction factor, SF_a = uncorrected Janbu Method safety factor value, b1 = function of soil type, d = distance between L and the slip surface, L = straight line distance between the ends of the slip surface, c = Soil cohesion, b_n = Horizontal length of the n-th slice area, W_n = Force due to the n-th soil load, α = Angle between the

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midpoint of the slice area and the center point of the sliding plane, φ = Internal friction angle, u = Pore water pressure, F = Fellenius method safety factor value.

The research continued by designing a cantilever retaining wall on the slope of the research area to obtain a stable slope safety factor value. Cantilever wall are a type of retaining wall that is commonly used to support relatively high levels of land. This type of wall is suitable for retaining soil up to 8 m high (Anonym, 2017). In supporting the soil behind it, a cantilever wall utilizes the weight of its own structure and the weight of the soil piled above its footprint. The heavier the structure and dimensions of the footprint behind the wall, the greater the resistance (Hakam, 2010).

The process in planning a retaining wall is as follows:

1. Determine the retaining wall design
2. Calculate the lateral earth pressure value

In this research, the lateral earth pressure method based on Rankine Theory (1857) was used. Lateral earth pressure analysis based on Rankine Theory (1857) is based on several assumptions, namely that the soil is in a position of plastic equilibrium, which means that every soil element is in a condition where it will collapse, the embankment soil behind the retaining wall is non-cohesive soil (c = 0) , and the surface of the retaining wall is considered perfectly smooth so that friction between the wall and the embankment behind it is neglected (δ = 0) (Hardiyatmo, 2006 in Amran & Kurniawan, 2017).

$$Pa = \frac{1}{2}\gamma H^2 Ka - 2cH\sqrt{Ka} \text{.........(4)}$$

$$Ka = cos\ \alpha . \left[\frac{cos\ \alpha - \sqrt{cos^2\alpha - cos^2\varphi}}{\cos\alpha + \sqrt{cos^2\alpha - cos^2\varphi}}\right] \text{.........(5)}$$

$$Pp = \frac{1}{2}\gamma H^2 K_p + 2cH\sqrt{K_p} \text{.........(6)}$$

$$K_p = tan^2\left(45 + \frac{\varphi}{2}\right) \text{.........(7)}$$

Information: Pa = Active soil pressure (kN/m), γ = Soil unit weight (kN/m^3), H = Height of the soil layer under consideration (m), Ka = Active soil coefficient in the layer under consideration, c = Soil cohesion (kN/m^2), α = slope angle of the soil layer (°), φ = Internal friction angle (°), Pp = Passive soil pressure (kN/m), K_p = Passive soil coefficient in the layer under consideration.

3. Calculate the vertical force and moment of resistance of the retaining wall
4. Calculate the stability of the retaining wall against overturning

$$FS_{ovt} = \frac{\Sigma M_R}{\Sigma M_o} \text{.........(8)}$$

$$\sum Mo = Ph\frac{(H')}{(3)} \text{......(9)}$$

Information: ΣM_R = moment of resistance (kN.m), ΣMo = overturning moment (kN.m), Ph = active soil pressure in the horizontal direction (kN/m), H' = height of the soil layer behind the retaining wall (m).

5. Calculate the stability of the retaining wall against sliding

$$FS_{sld} = \frac{\Sigma F_{R'}}{\Sigma F_d} \text{......(10)}$$

$$\Sigma F_{R'} = \Sigma V \tan(k_1\varphi_2) + Bk_2c_2 + P_p \text{......(11)}$$

$$\Sigma R_h = P_a \cos\alpha \text{......(12)}$$

Information: $\Sigma F_{R'}$ = total horizontal resistance force (kN), ΣFd = total horizontal active pressure (kN), ΣV = total vertical force acting (kN), k1 and k2 = multiplier constant (value 0.5 – 0.67) , φ_2 = friction angle in the foundation subsoil layer (kN/m^2), B = foundation base width (m), C_2 = cohesion of the foundation subsoil layer (kN/m^2), P_p = Passive soil pressure (kN/m), P_a= Active soil pressure (kN/m), α = slope angle of the soil layer (°)

6. Calculate the stability of the retaining wall to the soil bearing capacity

$$FS_{bear} = \frac{q_{ult}}{q_{max}} \text{......(13)}$$

$$q_{ult} = c\ x\ N_c + q\ x\ N_q + 0{,}5\ x\ \gamma\ x\ B\ x\ N_\gamma \text{......(14)}$$

$$q_{max} = \frac{\Sigma V}{B}\left(1 + \frac{6e}{B}\right) \text{......(15)}$$

$$e = \frac{B}{2} - \frac{\sum M_R - \sum M_o}{\sum V} \text{......(16)}$$

Information: FS_{bear} = safety factor for soil bearing capacity, qult = ultimate bearing capacity (kN/m^2), qmax = maximum bearing capacity (kN/m^2), c = soil cohesion (kN/m^2), q = γ x D (unit weight of soil x depth), B = dimensions of width or diameter of the foundation (m), φ = internal friction angle (°), Nc, Nq, Nγ are soil bearing capacity factors which depend on the value of φ, ΣV = number of vertical forces (kN), B = width of the foundation base (m), E = eccentricity (m), ΣM_R = moment of resistance (kN.m), ΣMo = overturning moment (kN.m).

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RESULT AND DISCUSSION

Slope in the Research Area

The slope in the research area are composed of three soil layers which are differentiated based on the level of weathering. Layers 1 and 2 have a CWZ (Completely Weathered Zone) weathering level, and Layer 3 has a HWZ (Highly Weathered Zone) level. Based on the USCS classification, layer 1 is composed of high plasticity clay soil (CH), layer 2 and layer 3 are composed of high plasticity silt soil (MH).

Physical and Mechanical Properties of Soil on Slope in the Research Area

The physical and mechanical properties of the slope-forming soil are obtained through laboratory testing. The physical properties of the soil required are the unit weight value obtained from the unit weight test, while the mechanical properties of the soil include cohesion and internal shear angle obtained through the direct shear test. The physical and mechanical properties of the soil on the slope of the research area are shown in table 1.

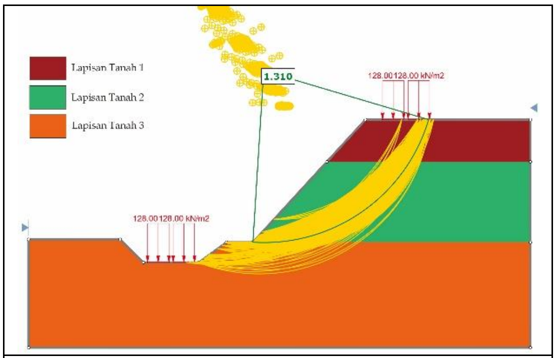
Table 1. Physical and Mechanical Properties of Soil Layer on Slope

Soil Layer	Unit Weight (kN/m^3)	Cohession (kN/m^2)	Internal Friction Angle (°)
Layer 1	18,51	40,805	22,71
Layer 2	18,54	43,473	28,03
Layer 3	18,51	38,305	26,93

Actual Slope Stability Analysis

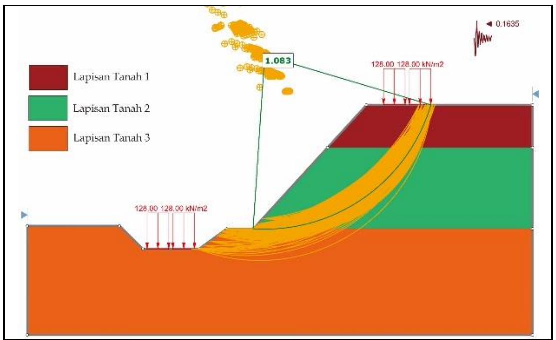
In the research area, the peak earthquake acceleration (PGA) value was obtained at 0.327 g. The horizontal earthquake coefficient value is equal to 50% of the PGA (Hynes-Griffin & Franklin, 1984 in Wyllie & Mah, 2005). The horizontal earthquake coefficient value is 0.1635 g. Based on the assumption that the largest vehicle that can pass the road on a slope is a truck with a total weight of 35 tonnes with 10 wheel specifications and a tire tread width of 11 inches, the vehicle load value is 128 kN/m2.

Calculation of the slope safety factor in actual conditions was carried out using Rocscience Slide 2 software. Based on the simulation results, the actual slope safety factor value obtained in static conditions with vehicle load was 1.31. This value is smaller than the FS slope criteria for static conditions of SNI 8460:2017, namely min 1.5. Meanwhile, the actual slope safety factor in pseudo-static conditions with vehicle loads is 1.083. This value is smaller than the FS slope criteria for pseudo-static conditions of SNI 8460:2017, namely min. 1.1. This condition causes the need for slope reinforcement to increase the safety factor.



Existing Slope	
Seismic Load: Static Failure Direction: Right to Left Analysis Method: Janbu	Overall Slope Slope Height: 16,74 m Slope: 41°
FS Value: 1,31	

Figure 1. Actual Slope Stability Simulation Result for Static Conditions with Vehicle Load



Existing Slope	
Seismic Load: Pseudo-static Failure Direction: Right to Left Analysis Method: Janbu	Overall Slope Slope Height: 16,74 m Slope: 41°
FS Value: 1,083	

Figure 2. Actual Slope Stability Simulation Result for Pseudo-static Conditions with Vehicle Load

Retaining Wall Design

On the slope, a cantilever type retaining wall with a wall height of 7 meters is applied. The foundation base of the planned retaining wall is 1.7 meters deep from the ground surface. The design of retaining wall refers to SNI 8460:2017 with the design plan shown in Figure 3.

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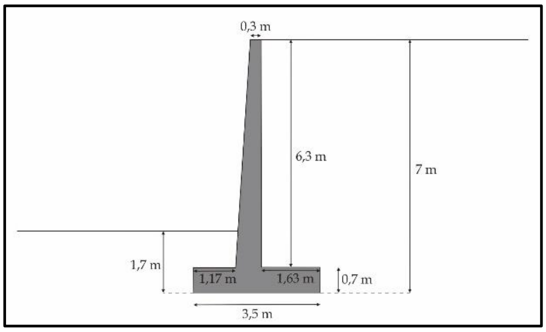

Figure 3. Design of Cantilever Retaining Wall

In calculating the stability of a retaining wall, it is planned to use non-cohesive fill soil behind the retaining wall. In cohesive soils such as clay, increasing water content causes a decrease in soil shear strength and an increase in lateral soil pressure, so the use of granular soil as backfill material behind retaining wall is more recommended because water content does not affect the shear strength of the material (Hardiyatmo, 2011 in Pradana et al., 2017).

The non-cohesive backfill material used has an unit weight (γ) of 20 kN/m3, cohesion (c) of 0 kN/m2, and an internal friction angle (φ) of 35° referring to the sandy soil sample of granular material by (Souza Junior et al., 2017). The concrete used is normal concrete material with a unit weight (γ) of 25 kN/m2 based on SNI 03-2847-2002.

Calculation of Lateral Earth Pressure

Based on Rankine Theory, the total active earth pressure (Pa) value acting on the retaining wall is 132.79 kN/m, while the total passive earth pressure (Pp) value acting on the retaining wall is 283.29 kN /m.

Calculation of Vertical Force and Moment of Resistance

From the calculations, the value of the vertical force (ΣV) acting on the retaining wall is 345.80 kN/m, while the moment of resistance (ΣMR) acting on the retaining wall is 785.68 kN.

Table 2. Calculation of Vertical Force and Moment of Resistance

Weight	Area (m2)	Vertical Forces (kN/m)	Moment Arm Measured from O (m)	Moment (kN)
W1	1,89	47,25	1,72	81,11
W2	1,26	31,50	1,43	45,15
W3	2,45	61,25	1,75	107,19
W4	10,29	205,80	2,68	552,23
ΣV = 345,80 kN/m			ΣMR = 785,68 kN	

Stability of Retaining Wall Against Overturning

From the calculations, the value of the safety factor against overturning (FSovr) of the retaining wall is 2.54. This safety factor value is greater than the SNI 8460:2017 safety factor criteria for overturning, namely a minimum value of 2. This shows that the retaining wall has been assessed as safe from overturning.

Stability of Soil Retaining Wall against Sliding

From the calculations, the value of the safety factor against sliding (Fsld) of the retaining wall is 3.65. This safety factor value is greater than the safety factor criteria for sliding SNI 8460:2017, namely a minimum value of 1.5. This shows that the retaining wall has been assessed as safe from sliding.

Stability of Retaining Wall on Soil Bearing Capacity

From the calculations, the value of the safety factor for the soil bearing capacity (FSbear) of retaining wall is 5.70. This safety factor value is greater than the safety factor criteria for bearing capacity of SNI 8460:2017, namely a minimum value of 3. This shows that the foundation soil has a good bearing capacity in supporting the retaining wall structure above it.

Analysis of Slope Stability with Retaining Wall

Calculation of the safety factor for slope with retaining wall was carried out using geotechnical software. Based on the simulation results, the value of the safety factor for slope with retaining wall in static conditions with vehicle loads was 1.53. This value meets the FS slope criteria for static conditions of SNI 8460:2017, namely min 1.5. Meanwhile, the actual slope safety factor in pseudo-static conditions with vehicle loads is 1.11. This value meets the FS criteria for pseudo-static slope conditions of SNI 8460:2017, namely min. 1.1.

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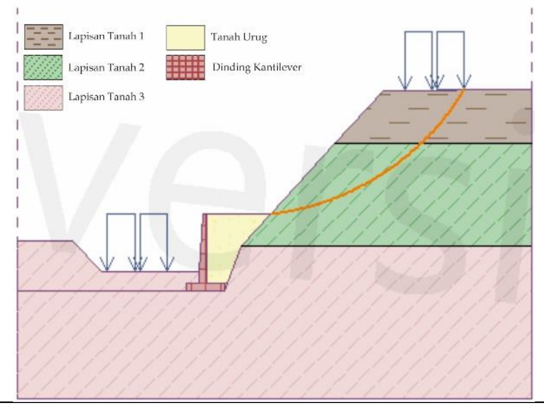
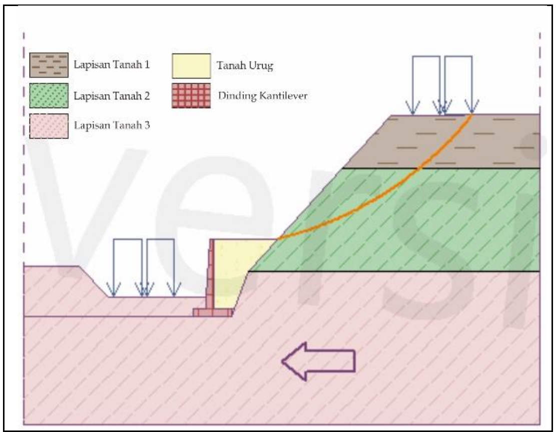


Slope with Retaining Wall	
Seismic Load: Static Failure Direction: Right to Left Analysis Method: Janbu	Overall Slope Slope Height: 16,74 m Slope: 42°
FS Value: 1,53	

Figure 4. Slope Stability with Retaining Wall Simulation Result for Static Conditions with Vehicle Load



Slope with Retaining Wall	
Seismic Load: Pseuodostatic Failure Direction: Right to Left Analysis Method: Janbu	Overall Slope Slope Height: 16,74 m Slope: 42°
FS Value: 1,11	

Figure 5. Slope Stability with Retaining Wall Simulation Result for Pseudo-static Condition with Vehicle Load

CONCLUSION

Based on the simulation results, the actual slope safety factor value in static conditions with a vehicle load is 1.31, while the actual slope safety factor value in pseudo-static conditions with a vehicle load is 1.083. The safety factor value based on these two conditions does not meet the slope FS criteria according to SNI 8460:2017. This causes the need for engineering on slope to increase the value of the safety factor. The slope engineering carried out is the use of cantilever retaining wall.

The cantilever wall are designed with a height of 7 m and the foundation base is 1.7 m deep from the ground surface. Based on the calculation results, the designed retaining wall has a stability value against overturning of 2.54, stability against sliding of 3.65, and stability for soil bearing capacity of 5.70. All three have met the FS SNI 8460:2017 criteria for the stability of retaining wall against overturning, sliding and soil bearing capacity. The simulation results for the value of the safety factor for slope with retaining wall show a value of 1.53 for static conditions with vehicle loads and 1.11 for pseudo-static conditions with vehicle loads. The safety factor value based on these two conditions meets the FS criteria for soil slope according to SNI 8460:2017.

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