U Karst
Volume 07 Number 01 Year 2023

ISSN (*Online*) 2581-0855
ISSN (*Print*) 2579-4620

Available Online at
https://ojs.unik-kediri.ac.id/index.php/ukarst/article/view/4554

https://doi.org/10.30737/ukarst.v7i1.4554

The Construction of a Gravity Retaining Wall to Prevent Landslides on the Grogol Kediri Highway

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ARTICLE INFO

Article History :
Article entry : 15 – 04 – 2023
Article revised : 17 – 04 – 2023
Article received : 30 – 04 – 2023

***Keywords* :**
Foundation, Landslide, Retaining Wall, Stability.

IEEE Style in citing this article:
N. Khalid, A. Derahman, R. Razali, N. A. Kamaluddin, "The Construction of a Gravity Retaining Wall to Prevent Landslides on the Grogol Kediri Highway,". U Karst, vol. 7, no. 1, pp. 119 – 134, doi: 10.30737/ukarst.v7i1.4554

ABSTRACT

One proof of Kediri's progress is the construction of Doho Kediri International Airport which is expected to improve the economy and tourism in this city. The airport was built with the aim of improving connectivity and suppressing development disparities in southern East Java. The purpose of this study is to plan the construction of an earthquake-resistant which is gravity retaining wall on the Grogol Kediri Highway, Kediri Regency. . Planning is carried out at STA 3.8-4.0. , soil laboratory testing on samples obtained from the studied location. Identification of the soil type, sliding angle, and weight of the soil volume at the site are needed to determine the planning of earthquake-resistant retaining walls. From the soil properties obtained, it can be determined that the land is included in the GC (Clayey Gravel) category With a shear angle of 28° and a weight of 1.463 gr/cm3. These results were used to calculate the dimensions and the stability of the retaining wall using the Coulomb method. The retaining wall should have a peak body width of 1 meter, foundation width of 3.8 meters, foundation thickness of 1 meter, foundation depth of 1.04 meters, foot and heel width of 0.9 meters, height of 6 meters, and bottom body thickness of 2 meters. Based on stability calculations, the retaining wall is safe against overturning, shifting, and subsidence. Therefore, this retaining wall is a viable solution to prevent landslides and mitigate the negative impacts caused by them.

1. Introduction

Kediri has become a city that shows development in various aspects, be it infrastructure, tourism, economy, and so on. One proof of Kediri's progress is the construction of Doho Kediri International Airport which is expected to improve the economy and tourism in this city [1]. With the existence of Doho Kediri International Airport, the city of Kediri will be increasingly connected to various major cities in Indonesia and abroad, so as to increase economic and industrial growth in the city [2], [3]. The airport was built with the aim of improving connectivity and suppressing development disparities in southern East Java. Dhoho Kediri International Airport is located in Grogol District, Kediri Regency.

Grogol District has a topography in the form of plateaus and hills which cover the Kalipang and Grogol village areas. Kalipang Village is the only connecting road between Kalipang Village and the Grogol District. This road will facilitate the mobility of the local community. This region has hilly land contours and tends to be steep. This makes road access to these villages sometimes difficult to pass, especially in the rainy season due to the potential for landslides and floods [4]. A landslide is the movement of slope-forming material that moves down or out of the slope [5], [6]. Slope material that closes the road can endanger and harm residents and road users [7], [8]. Kalipang Village often experiences landslides resulting in cutting off road access and damaging several people's houses [9]. This causes considerable material and nonmaterial losses [10], [11].

Slope must be ensured to be stable to prevent landslides [12]. To ensure the stability of the slope, geotechnical analysis and observation of factors that can affect the stability of the cliff are needed. Slope stability can be improved by adjusting the slope [13], [14].In addition, regular supervision and maintenance are also needed, including the construction of retaining structures such as retaining walls. However, unfortunately, some areas in Kalipang Village do not have adequate infrastructure to prevent landslides.

The soil retaining wall serves to prevent soil masses indicated by landslides [15]. Soil retaining walls that are often used in construction projects are gravity, cantilevers, and sheet piles. A gravity retaining wall is a wall construction that supports and withstands the pressure of the material (soil) behind it [16], [17]. Gravity retaining walls are designed to withstand the lateral force load of the soil so that the danger of landslides that may occur can be avoided [18]. Gravity retaining walls are important structural components of buildings for highways and other environmental buildings related to contoured soils or soils with different elevations [19], [20]. In planning a gravity retaining wall or other types of retaining wall construction, it is necessary to consider the size and place where lateral soil pressure works. Thus the planned gravity retaining wall will withstand the pressure safely [21]. Identification of the soil type, sliding angle, and weight of the soil volume at the site are needed to determine the planning of earthquake-resistant retaining walls [22]. Some research outlines that building earthquake-resistant retaining walls is needed on a slope [23], [17].

This study aims to design an earthquake-resistant gravity retaining wall to anticipate landslides on Grogol Highway. The study was conducted based on the calculation analysis of stability on the retaining structure. Several considerations were considered in the stability

https://dx.doi.org/10.30737/ukarst.v7i1.4554

ISSN (*Online*) 2581-2157
ISSN (*Print*) 2502-9304

analysis, such as the dimensions and stability of the earthquake-resistant gravity retaining wall. It is hoped that by planning this retaining wall, landslides can be prevented and negative impacts can be avoided.

2. Research Method

This study was conducted at Grogol Highway at STA 3.8 – 4.0 KM. The Coulomb method of analysis was selected to determine the stability of gravity retaining walls, including the dimensional design and stability of earthquake-resistant retaining walls. Several data were collected in this study to be used in the stability analysis, such as technical data and soil properties data obtained from soil testing and field surveys.

2.1 Data Collection

Some of the data collected include planning technical data, soil characteristic data, and active forces on earthquake-resistant gravity retaining walls:

a. Planning Technical Data

For this study, the main technical data is planned at a location in Kalipang Village, Kec. Grogol Kab. Kediri precisely on Grogol STA Highway 3.8 km to 4.3 km, as shown in **Table 1.**

Table 1. Technical Data

Data	Value
Slope Height, (m)	5.0
Slope Ratio	1:4
Load surcharge, (tons/m^2)	20
Concrete Weight, (tons/m^3)	2,4
Sliding ability (τ), (tons/m^2)	15
Tensile ability (Ơtarik), (tons/m^2)	30
Concrete press strength (Ơbk), (tons/m^2)	150

Source : Author

b. Soil Characteristics Data

From laboratory testing, the soil test results were obtained which are presented in **Figure 1** and **Table 2**.

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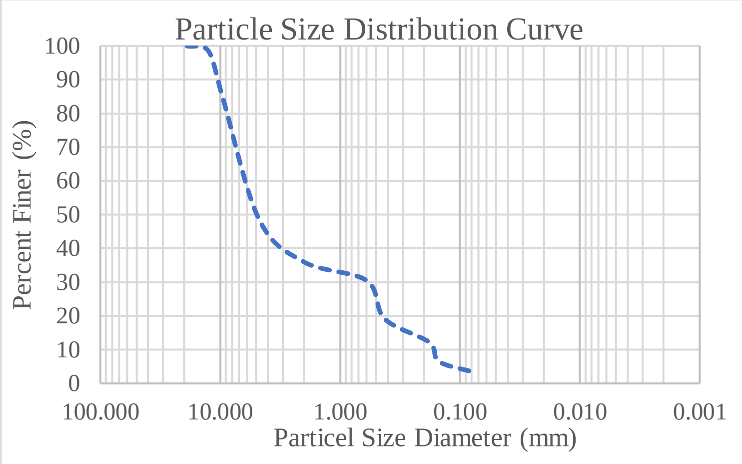


Source : Laboratory Testing Results by the Author.

Figure 1. Particle Size Distribution Curve.

From the particle size distribution curve above, the Cc (Curvature Coefficient) value is 0.333 and the Uniformity Coefficient (Cu) is 37.122.

Table 2. Soil Properties.

Data	Value
Liquid limit (LL), (%)	43.43
Plastic limit (PL), (%)	7.42
Plastic Index (PI), (%)	36.01
Soil Activity	4.8
Weight of Soil, (kN/m^3)	14,347
Shear Angle, (^{0})	28
Soil group/categories	Clay pebbles, gravel-sand-clay mixture

Source : Laboratory Testing Results by the Author.

From the soil properties obtained, it can be determined that the land is included in the GC (Clayey Gravel) category. This is because it is classified as coarse-grained soil because more than 50% is retained by sieve number 200 [24]. Included in Gravel is because more than 50% of the coarse fraction is retained by no. 4 and classified as GC because it has a PI of more than 7.

2.2 Active Force on Earthquake Resistant Ground Retaining Wall

The parameters of the earthquake selection of bedrock earthquakes are established from spectral responses of 0.2 and 1 second in seismic soil motion maps expressed in decimal numbers to gravitational acceleration. Earthquakes are taken and calculated from http://puskim.pu.go.id/ data. Based on the coordinates of Raya Grogol Street location is at latitude: -7.7667115 and longitude: 111.9216963 with earthquake acceleration result (Ss) = 0.799.

https://dx.doi.org/10.30737/ukarst.v7i1.4554

ISSN (*Online*) 2581-2157
ISSN (*Print*) 2502-9304

The active force acting behind the retaining wall is required to identify the magnitude of the active force value due to the earthquake and the location of the working line. The active force acting behind this retaining wall affected the design of the retaining wall structure to be built [21][22][23]. Therefore, the consideration for the active force parameter acting behind the retaining wall in this study was selected, as shown as in **Table 3**.

Table 3. The consideration for active forces parameter behind the wall

Data	Value
The inertial force for the vertical direction (k_v) and horizontal (k_h)	0.082
Active soil coefficient (K_a)	0.372
Active force per unit width of the wall ($\boldsymbol{Pae}$), *kN/m*	59.84
Resultant location of the work line ($\bar{z}$), *m*	1.64

Source : Laboratory Testing Results by the Author.

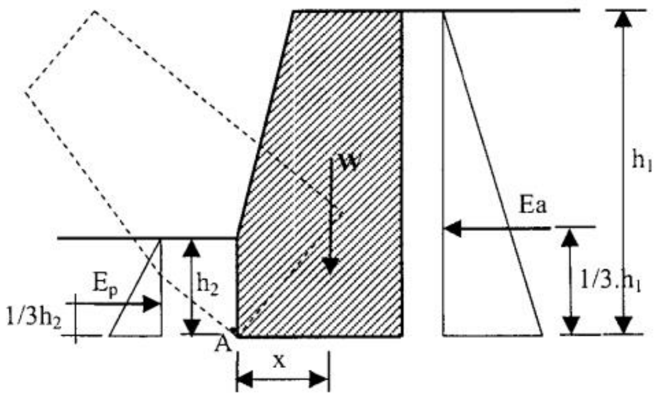
2.3 Analytical Techniques

2.3.1 Construction Stability

Stability assessment of the retaining structure of the soil becomes important in planning the structure of the retaining wall. Some of the things that are done to check the stability of the retaining wall are described as follows:

- **Safe Against the Dangers of Overturning**

  The structure of the retaining wall must be able to withstand the moment of rolling. This meant safety against the danger of overturning. Therefore, the comparison result of the holding moment (Mp) with the moment of overturning (Mg) must be greater than 1.50. The holding moment or roll moment is calculated against the turning point of the roll (A), as in **Figure 3**. [25].



Source: Foundation Engineering II, Dr. Bambang Surendro (2014) [25]

Figure 2. Ground Retaining Wall Roll Sketch

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Mg = Ea . 1/3.h1 – Ep . 1/3.h2

Mp = W . x

Safe when: Mp / Mg ≥ 1.50

- **Safe Against the Dangers of Sliding**

The structure of the retaining wall must be able to withstand the force. This means safely against the danger of sliding [25].

So that $n = \frac{\sum W.f}{\sum Ea} \geq 1.50$

With f = swipe coefficient = tg φ

- **Safe Against Downside Hazards**

In addition to being safe against the dangers of overturning and sliding, the construction of retaining walls must also be safe against the threat of subsidence. The requirement for construction that is safe against the danger of settlement is that the point of intersection of the resultant forces must still be within the core of the foundation or the value of eccentricity (e) ≤ 1/6 b [25].

$$e = \frac{\sum M}{\sum W}$$

With ΣM is number of moments of all forces against the center of the foundation weight; and ΣW is number of vertical forces.

The maximum pressure that arises must not exceed the carrying capacity of the land permit (σ) or $\sigma > \sigma'$. Maximum voltage embossed (σ') can be calculated by the following equation:

$$\sigma_{max} = \frac{V}{A}\left(1 \pm \frac{6.e}{b}\right)$$

With: A = b . L (viewed 1 m perpendicular to the image field)

2.3.2 Construction Strength Stability

- **Stability Body Strength**

The following steps can calculate the stability of the body strength:

1. The body is calculated like a hanging load clamped by the legs.
2. The calculated force is the force acting on the foot.
3. (L) viewed 1 m perpendicular to the drawing plane.
4. The normal force is taken from the sum of the vertical forces (ΣW).
5. Moments are calculated based on the centre of gravity of the body.
6. The following equation is used to calculate the magnitude of the stress that occurs in the structure:

https://dx.doi.org/10.30737/ukarst.v7i1.4554

ISSN (*Online*) 2581-2157
ISSN (*Print*) 2502-9304

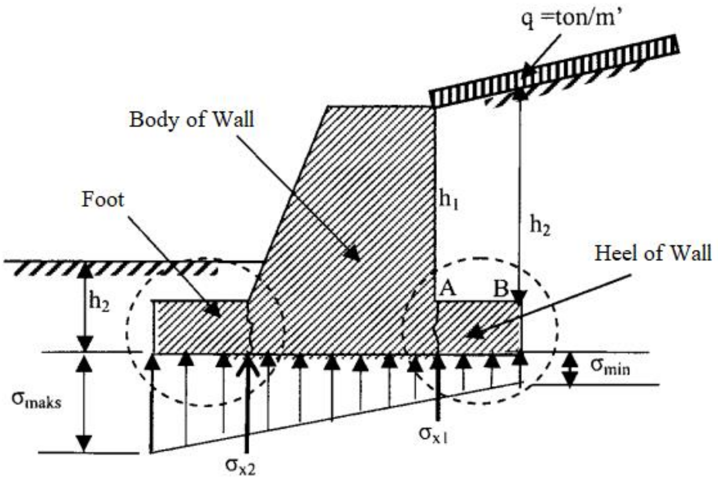
$$\sigma_{max} = \frac{V}{b.L} + \frac{M}{\frac{1}{6}b^2L} \leq \sigma'$$

$$\sigma_{mn} = \frac{V}{b.L} - \frac{M}{\frac{1}{6}b^2L} \leq \sigma'$$

- **Strength Leg/Heel Stability**

The strength at the base of the foot/heel is used to calculate the stability of the foot/heel strength. With steps like the following:

1. The toe/heel part is considered with a pinched bar.
2. (L) foot/heel viewed 1 m perpendicular to the drawing plane.
3. The ground pressure above the foot/heel (W), the ground pressure under the foot/heel (σ), and the self-weight of the foot/heel (Ws) are the forces acting on the foot/heel.
4. The stability of the foot/heel refers to the two forces acting, namely the shear force (D) and the pure moment at the base of the foot.
5. The foot/heel is considered safe when it has a shear capability > of its shear force ($\tau > \tau'$) [25]



Source: Foundation Engineering II, Dr. Bambang Surendro (2014) [25]

Figure 3. Crack-Prone Wall Parts.

$$\tau = \frac{3}{2} . \frac{D}{d.L}$$

With τ is Shearing Force; τ′is Shearing Force; D is Shearing Force; d is foot/heel thickness; L is length of the foot/heel in 1 m perpendicular to the drawing plane.

The magnitude of the force acting on the heel can be seen in the pressure diagram as follows:

q1 = h1 . γ soil

q2 = h1 . γ soil

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d1 = d . γ couple

d2 = d . γ couple

And for the stress that arises can be calculated by the equation:

$$\sigma = \frac{V}{A}\left(1 \pm \frac{6.e}{d}\right)$$

Comparisons that apply to triangles and trapezoids can be used to find the value of σ_{x1} and σ_{x2}. Therefore, the magnitude of the calculated force is as follows:

a = q1 + d1 - σ_{x1}

b = q2 + d2 - σ_{x2}

With the sum of the forces calculated by the equation:

$$D = \left(\frac{a+b}{2}\right).e.L$$

The calculation of value of the moment acting on the heel can be calculated in the following way:

P1 = a . e . L

P2 = ½ . (b – a) . e . L

M = P1 . (1/3 . e) + P2 . (2/3 . e)

W = 1/6 . L . d^2

$$\sigma = \frac{M}{W} < \sigma \text{ tensile concrete masonry (foot safety)}$$

3. Results and Discussions

3.1 Retaining Wall Dimensions

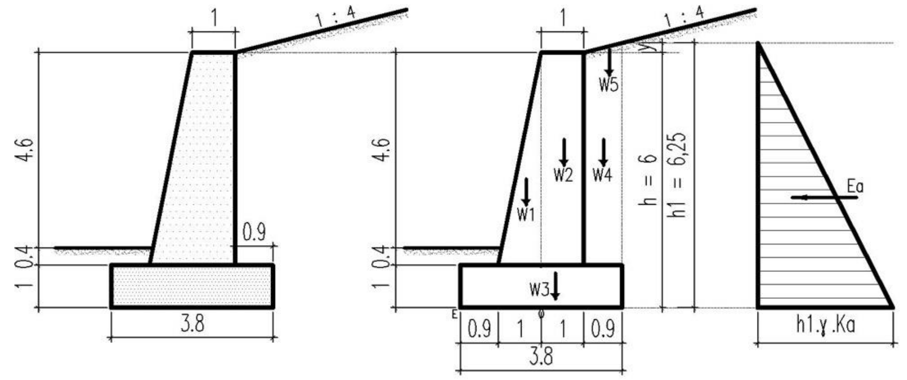
The proposed dimensions of the gravity retaining wall used in this study at STA 3.8 - 4.0 KM as shown in **Table 4**, and the schematic diagram of the retaining wall is shown in **Figure 4**.

Table 4. The dimension for STA retaining wall structure at 3.8 – 4.0 KM.

Data	Value
Peak width (a), m	1.0
Foundation base width (b), m	3.8
Foot thickness (d), m	1.0
Foot/heel width (e), m	0.9
Foundation depth (D_f), m	1.04
Wall height from the base of the foundation (h), m	6.0
Wall body width (t), m	2.0

Source: Author Analysis.

ISSN (*Online*) 2581-2157
ISSN (*Print*) 2502-9304



Source: Author Analysis.

Figure 4. Dimensions size for STA Retaining Wall at 3.8 – 4.0 KM

3.2 Construction Stability Calculation

The calculation of the stability of the retaining wall construction at STA 3.8 – 4.0 KM is described as follows:

a) Active soil coefficient (Ka)

The value of the active soil coefficient (Ka) is 0.372

b) Horizontal Force

$Ea = ½. \gamma. H^2. Ka = ½ . 1,463. 6,25^2 . 0,372 = 10.63$ ton

Arm to turning point E (ya) = 1/3. 6.25 = 2.08 m

ME = Ea. ya = 10.63 . 2.08 = 22.11 ton.meter

The calculation above resulting to a horizontal pressure (Ea) of 10.63 tons and a Moment (ME) of 22.11 ton.meters.

Table 5. Vertical Force Sta Ground Retaining Wall 3.8 – 4.0 KM

Name	Force (ton)	Arms Facing point E (m)	Moment = Force x Arm (ton meter)
(1)	(2)	(3)	(4) =(2) x (3)
W1	6.00	1.567	9.4
W2	12	2.4	28.8
W3	9.12	1.9	17.328
W4	6.5835	3.35	22.055
W5	0.165	3.500	0,5761
ΣW	**33.87**		**78,159**

Source: Data processed.

From **Table 5** the value (ΣW) = 33.87 tons, with the value of the holding moment (MP) = 78.159 tons of meters, and the moment of overturning (MG_1) = 22.11 tons of meters.

c) Check against the overturning

Checks against overturning are obtained by dividing the Moment of Restraint (MP) by the Moment of overturning (MG). Retaining Wall is said to be safe if the result of the division is greater than the security figure (1.5).

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$$n = \frac{MP}{MG} = \frac{78{,}159}{22{,}145} = 3.529 \; > 1.50 \textbf{ (safe)}$$

d) Check against sliding

A sliding check is obtained by dividing the number of forces that hold (ΣW) by the number of sliding forces (ΣE). Retaining Wall is said to be safe if the result of the division is greater than the security figure (1.5).

$$n = \frac{\Sigma W}{\Sigma E} = \frac{33{,}87}{10{,}63} = 3.186 > 1.50 \textbf{ (safe)}$$

Table 6. Check for Subsidence of Retaining Walls STA 3.8 – 4.0 KM

Name	Force (ton)	Arm Against point O (m)	Moment = Force x Arm (ton meters)
(1)	(2)	(3)	(4) = (2) x (3)
W1	6.00	0.3333	2
W2	12	0,5	6
W3	9.12	0	0
W4	6.5835	0.95	6.254325
W5	0.165	1.1000	0.1810
ΣW	**33.87**		**14.435**

Source: Author Analysis.

Table 6 obtained a value (ΣW) = 33.87 tons, with the value of the moment of overturning (MG_2) = 14.435 tons of meters. From these results, the number of moments of all forces (ΣM), eccentricity (e), and voltage arising can be calculated as follows:

ΣM = MG_1 - MG_2

= 22.110 – 14.435

= 7.675 ton meter

Eccentricity (e) $= \frac{\Sigma M}{\Sigma W} = \frac{7{,}710}{33{,}87}$

= 0.028 < 1/6b = 0.633 **(safe)**

Ơ max $= \frac{\Sigma W}{A}\left(1 + \frac{6\,.e}{b}\right) = \frac{33{,}87}{3{,}8}\left(1 + \frac{6\,.\;0{,}028}{3{,}8}\right)$

= 12.116 ton/m² < 20 ton/m² **(safe)**

Ơ min $= \frac{\Sigma W}{A}\left(1 - \frac{6\,.e}{b}\right) = \frac{33{,}87}{3{,}8}\left(1 - \frac{6\,.\;0{,}028}{3{,}8}\right)$

= 5.709 ton/m² < 20 ton/m² **(safe)**

From the above calculations, it is declared safe to decrease because the maximum voltage value (Ơ mak) is 12.116 tons / m² and the minimum voltage (Ơ min) is 5.709 tons / m². The value is smaller than the land permit's carrying capacity, which is 20 tons / m², so it is declared safe.

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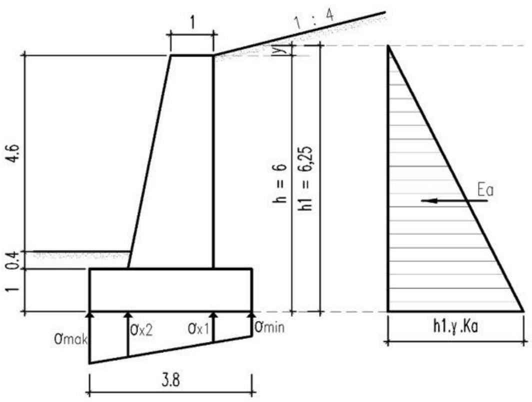
3.3 Calculation of Construction Strength Stability

Calculating the stability of the construction strength is needed to check the parts of the construction that are prone to cracking, including the body, feet, and heels.

a) Check for construction strength.



Source: Author Analysis.

Figure 5. Retaining Wall Construction STA 3.8 – 4.0 KM

$Ơx_1$ $= Ơmin + \left(\frac{Ơmax - Ơmin}{b}\right)$. wide W4 $= 5{,}709 + \left(\frac{12{,}116-5{,}709}{3{,}8}\right) . 0{,}9$

$= 7{,}227$ ton/m²

$Ơx_2$ $= Ơmin + \left(\frac{Ơmax - Ơmin}{b}\right)$. wide b - W4 $= 5{,}709 - \left(\frac{12{,}116-5{,}709}{3{,}8}\right) . 2{,}9$

$= 10{,}599$ ton/m²

b) Heel Strength

1. Shear Strength

h1 = h2 = h + y = 5 + 0,25 = 5.25 m

q1 = q2 = h1 . ɣ soil = 5.25 . 1.463 = 7.681 ton/m²

d1 = d2 = d . ɣ concrete = 1 . 2,4 = 2.4 ton/m²

$Ơx_1$ = 7.227 ton/m²

Ơmin = 5.709 ton/m²

a = q1 + d1 - $Ơx_1$ = 2.854 ton/m²

b = q2 + d2 – Ơmin = 4.372 ton/m²

D = ½ . (a + b) . e . l = ½ . (2.854 + 4.732). 0.9 . 1 = 3.252 ton

τ = 3/2 . (D/(d . l)) = 3/2. (3.252/ (1 . 1))

= 5.419 ton/m² < (shear ability 15 ton/m²) **(safe)**

From the calculation of the shear strength at the heel, a value of 5.419 tons/m² is obtained, where this value is smaller than the limit value for shearing ability, which is 15 tons/m², so that the construction is declared safe against sliding.

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2. Tensile strength

P1 = a . e . l = 2,854 . 0,9 . 1 = 2.569 ton

P2 = ½ . (b-a) . e . l = ½ . (4.372 – 2.854) . 0.9 . 1 = 0.683 ton

MI-II = (P1 . ½ e) + (P2 . 2/3 . e) = (2.596. ½ . 0,4) + (0.683. 2/3. 0.5)

= 0.741 ton

W = 1/6 . l . d^2 = 1/6. 1. 0.9^2 = 0.167 m^3

Ơ $= \frac{M}{W} = \frac{0,741}{0,167}$ = 4.448 ton/m^2 < (Ơtarik 30 ton/m^2) **(safe)**

From the calculation of the tensile strength at the heel, a value of 4.448 tons/m^2 is obtained, which is smaller than the limit value of the tensile strength of concrete, which is 30 tons/m^2, so the construction is declared safe.

c) Leg Strength

1. Shear Strength

h1 = h2 = 0,4 m

q1 = q2 = h1 . ɣ soil = 0,4 . 1.463 = 0.585 ton/m^2

d1 = d2 = d . ɣ concrete = 1 . 2.4 = 2.4 ton/m^2

Ơx_2 = 10,599 ton/m^2

Ơmax = 12,116 ton/m^2

a = q1 + d1 - Ơx_2 = 9.131 ton/m^2 (direction up)

b = q2 + d2 – Ơmax = 7.613 ton/m^2 (direction up)

D = ½ . (a + b) . e . l = ½ . (9.131 + 7.613). 0.9 . 1 = 7.535 ton

τ = 3/2 . (D/(d . l)) = 3/2. (7.535/(0,9 . 1))

= 11.302 ton/m^2 < (shear ability 15 ton/m^2) **(safe)**

From the calculation of the shear strength of the legs, a value of 11.302 tons/m^2 is obtained, which is smaller than the limit value of the shear capability, which is 15 tons/m^2, so that the construction is declared safe against sliding.

2. Tensile Strength

P1 = b . e . l = 7,613. 0,9. 1 = 6.852 ton

P2 = ½ . (b-a) . e . l = ½ . (7.613 – 9.131) = 0.683 ton

MI-II = (P1 . ½ e) + (P2 . 2/3 . e) = (6.852 . ½ . 0.4) + (0.683 . 2/3 . 0.5)

= 1.598 ton

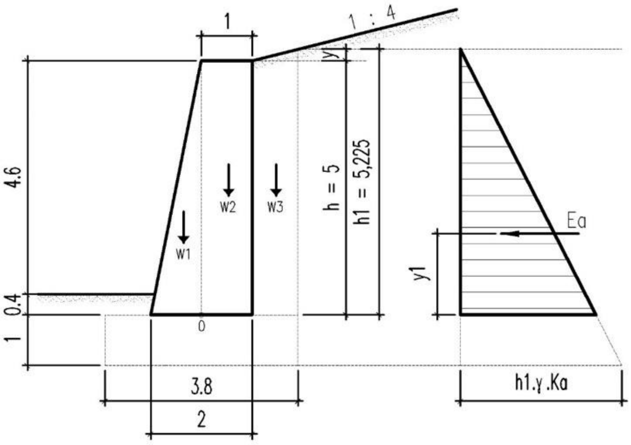
W = 1/6 . l . d^2 = 1/6. 1. 0.9^2 = 0.167 m^3

Ơ $= \frac{M}{W} = \frac{1.598}{0.167}$ = 9.588 ton/m^2 < (Ơtensile 30 ton/m^2) **(safe)**

ISSN (*Online*) 2581-2157
ISSN (*Print*) 2502-9304

From the calculation of the tensile strength on the legs, it is obtained that 9.588 tons/m², where this value is smaller than the concrete tensile strength limit of 30 tons/m², so the construction is declared safe.

d) Body Strength



Source: Author Analysis.

Figure 6. Body Strength STA 3.8 – 4.0 KM

y	= ¼ . 0.9	= 0.225 m	
Ea	= ½. γ. h1². Ka	= ½ . 1.463 . 5.225² . 0.372	= 7.4 ton
Arm against point (O) y1	= 1/3. h1	= 1/3 . 5.225	= 1.742 m
Ma	= Ea . y1	= 7.4 . 1.742	= 12.939 ton.meter

Table 7. Body Moment of Weight Point O

Number	Load (tons)	Arm against point O (m)	Moment against point O (ton meter)
1	6.00	0.3333	2
2	12	0.5	6
3	6.748	1.1000	7.423
	24.748		11.423

Source: Author Analysis.

ΣM = MA – MP = 12.939 – 11.423 = 1.516 ton meter

$$Ơ' = \frac{V}{A} + \left(\frac{M}{\frac{1}{6}.\ L\ .\ d^2}\right) = \frac{24.748}{2} + \left(\frac{1.516}{\frac{1}{6}.\ 1\ .\ 1^2}\right) = 21.470 \text{ ton/m}^2 < 150 \text{ ton/m}^2$$

(compressive strength of concrete characteristics) **(safe)**

$$Ơ = \frac{V}{A} - \left(\frac{M}{\frac{1}{6}.\ L\ .\ d^2}\right) = \frac{24.748}{2} - \left(\frac{1.516}{\frac{1}{6}.\ 1\ .\ 1^2}\right) = 3.278 \text{ ton/m}^2 < 30 \text{ ton/m}^2$$

(tensile strength of concrete) **(safe)**

From the calculation of the strength of the body, the maximum stress value is 21.470 tons/m². This value is smaller than the limit value for the compressive strength of concrete

https://dx.doi.org/10.30737/ukarst.v7i1.4554

ISSN (*Online*) 2581-2157
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ISSN (*Print*) 2502-9304

characteristics, which is 150 tons/m². And the minimum stress is 3.278 tons/m², which is also smaller than the limit value of the tensile strength of concrete, which is 30 tons/m², so that the body's construction is declared safe.

4. Conclusion

To provide slope stabilization along the Grogol highway in Kalipang village, which is characterized by GC (Clayey Gravel) soil, a gravity retaining wall can be constructed. The retaining wall should have a peak body width of 1 meter, foundation width of 3.8 meters, foundation thickness of 1 meter, foundation depth of 1.04 meters, foot and heel width of 0.9 meters, height of 6 meters, and bottom body thickness of 2 meters. Based on stability calculations, the retaining wall is safe against overturning, shifting, and subsidence. Therefore, this retaining wall is a viable solution to prevent landslides and mitigate the negative impacts caused by them.

https://dx.doi.org/10.30737/ukarst.v7i1.4554

ISSN (*Online*) 2581-2157
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