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Model of Timber Crib Walls Using Counterweight in Bone Bolango Regency Gorontalo Province Indonesia

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Abstract – *Crib wall is one type of retaining wall that is often done for slope reinforcement. Usually made of pre-cast concrete beams mounted interlocked-hooks with considerable construction costs. Based on that it is necessary to research the construction of slope reinforcement with low cost and easy in its implementation. The purpose of this research is to design crib wall by utilizing the local material. The research location is the slope of Trans Sulawesi-Pantai Selatan Street, precisely the slope of the road in Muara Bone Village (Bone Subdistrict) and Oluhuta Village (Kabila Bone Subdistrict), Bone Bolango Regency. Crib wall material used is timber obtained from around the research area. Slope stabilization analysis was performed using limit equilibrium with the help of Slide3 2017. The results of external and internal stability analysis showed that the slopes with the construction of timber crib walls in stable condition (Factor of Safety, FS>1.5). It is expected that the crib wall model can be an alternative to stabilize the roadside slopes in Bone Bolango District, due to the cheaper construction cost compared to other conventional retaining wall construction.*

Keywords: *Timber Crib Walls, Slope Stability, Factor of Safety, Limit Equilibrium Methods, Counterweight of Slopes*

Nomenclature

λ_{ah}	Coefficient of horizontal active lateral pressure
α	Inclination angle
β	Slope
δ	Angle of inclination of earth pressure
E_{ah}	Total horizontal earth pressure
γ	Unit weight
H	Height of slope
FS	Factor of safety
3D3	Dimension
2D2	Dimension
ΣM_r	Sum of resisting moment
ΣM_s	Sum of moment leading to overturning
ΣF_v	Sum of vertical forces
ΣF_r	Sum of resisting forces
$\Sigma F_{s.}$	Sum of disturbing forces
A	Area of wall base
B	Breadth of wall base
e	Eccentricity
σ	Stress
z	height of crib wall
N^*_B	Weight of fill material between crib layers (earth side)
N^*_A	Weight of fill material between crib layers (earth side)
$N_{A,B}$	Normal component of forces on the joints (for inclined wall)
G_1	Frictional force from silo pressure
G_3	Weight of crib elements
B'	Tensile force at the earth side crib element due to horizontal component of earth pressure
E_h	Horizontal earth pressure
h_E	Vertical height from the base to the assumed point of action of the resultant
k	Reduction factor
j	Reduction in mobilization of friction factor
a	Length of the crib cell
b	Width of the crib cell
a'	Effective base length of crib wall
b'	Effective base width of crib wall
N	Normal force due to self-weight of soil and crib wall
E_{VN}	Vertical component of earth pressure from backfill
F_{LC}	Safety factor against the lifting up of crib element
F_{CJ}	Safety factor against the breaking of joints element
γ_b	Bulk unit weight
c'	Effective cohesion
φ'	Angle of effective internal friction
E	Young's modulus
μ	Poisson's ratio
w	Water content
m	Moisture content
ρ	Density
F_c'//	Compressive strength

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F_v'// Shear strength
GLE General limit equilibrium

I. Introduction

Landslide events frequently occur in mountainous areas such as Bone Bolango District. That becomes a challenging task because it has repeatedly been done to improve the stability of the slope. During this method commonly used is the reinforcement of slopes with the conventional retaining wall, which is the wall of a stone-clutch. Also, this retaining wall, such as reinforcement of concrete walls, is often used for slope reinforcement.

Construction costs are quite expensive. Based on this it is necessary to model slope retrofitting using local materials. Utilization of materials in crib wall design is expected to reduce the cost of construction, in addition to a natural building.

The occurrence of the landslide in Bone Bolango regency, especially the roadside slope of Trans Sulawesi-Pantai Selatan Street caused by the geological condition and local topography. The structure of the rock easily landslides with a very steep hill. Andesite rocks on the slopes of Oluhuta Village, Kabila Bone subdistrict, have been destroyed and weathered due to the discontinuity. This zone is a zone passed by active fault [1], [2]. Several studies have been conducted by researchers on the design and analysis of crib walls as done by [3]-[9] and so on. References [5] and [8] research the numeric simulation of crib wall, while [6] and [7] investigate the failure of the crib wall. The studies of 3D equilibrium limit method analysis have also been widely used, as did by [11]-[18]. This 3D analysis is a development of 2D analysis.

II. Literature Review

II.1. Crib Walls

Crib walls are gravity retaining walls, a structure built up of longitudinal and transverse elements to form a series of rectangular cells into which infill is placed. Crib constructed from interlocking, precast, concrete components.

They are filled with free draining material and earth backfill to eliminate the hazards of hydrostatic pressure building up behind the wall. Crib wall elements can be made of concrete, steel, bamboo, or wood [4]. The spaces between the interlocking are filled with a granular material, i.e., sand, or aggregate [6]. Failure for the wall will be by one of the following modes:

1. Sliding and overturning of wall
2. The overstress on foundation (bearing capacity failures)
3. Sliding and overturning of crib elements
4. Overloading of crib elements and shearing of joints

The coefficient of active lateral pressures used in this analysis are calculated using the following equation after Coulomb's earth pressure theory [4]:

$$\lambda_{ah} = \frac{\cos^2(\varphi+\alpha)}{\cos^2\alpha\left[1+\sqrt{\frac{\sin(\varphi+\delta)\sin(\varphi-\beta)}{\cos(\alpha-\delta)\cos(\alpha+\beta)}}\right]^2} \tag{1}$$

and:

$$\lambda_a = \frac{\lambda_{ah}}{\cos(\alpha-\delta)}$$

The resultant earth pressure will be given by $E_{ah} = \frac{1}{2}\gamma H^2 \cdot \lambda_{ah}$, which will act at 1/3 of height from the bottom of the wall. In general, the factor of safety against slipping can be given by the equation:

$$FS = \frac{\sum Resisting\ Forces}{\sum Disturbing\ Forces} = \frac{F_r}{F_s} \geq 1.5 \tag{2}$$

The factor of safety against overturning is defined as:

$$FS = \frac{\sum M_r}{\sum M_s} \geq 2 \tag{3}$$

where ΣM_r=sum of resisting moment; ΣM_s=sum of moment leading to overturning. The maximum and minimum stresses at wall base are given by:

$$\sigma_{1,2} = \frac{\sum F_v}{A}\left(1 \pm \frac{6e}{B}\right) \tag{4}$$

where $\sum F_v$=sum of vertical forces; A and B=area and breadth of wall base; e=eccentricity [19]. The safety of a single crib element against the detachment from the crib system will be checked. In this case it is required to check the strength of joints. In case of inclined walls, the lifting up of crib elements can be happened in two ways [4]:

a. From vertical and horizontal forces (Fig. 1(b)). If A,B= self-weights of crib elements and soil trapped between crib layers in case of inclined crib wall, then total pressure on each side of crib elements can be calculated as follows:

$$\begin{aligned} Bb^*\cos\alpha &= N_B^*\left(\frac{z}{2}+\tan\alpha+b^*\cos\alpha\right) \\ &+G_3\left(\frac{z}{2}+\tan\alpha+\frac{b^*}{2}\cos\alpha\right)+N_A^*\frac{z}{2}+\tan\alpha \end{aligned} \tag{5}$$

$$\bar{B} = \frac{G_3}{2}+N_B^*+\frac{z}{2b^*}\frac{\tan\alpha}{\cos\alpha}(G_3+N_A^*+N_B^*)$$

$$\bar{A} = \frac{G_3}{2}+N_A^*-\frac{z}{2b^*}\frac{\tan\alpha}{\cos\alpha}(G_3+N_A^*+N_B^*)$$

$$\bar{A}+\bar{B} = G_3+N_A^*+N_B^*$$

For vertical walls:

$$\bar{A} = G_{3A}$$

and:

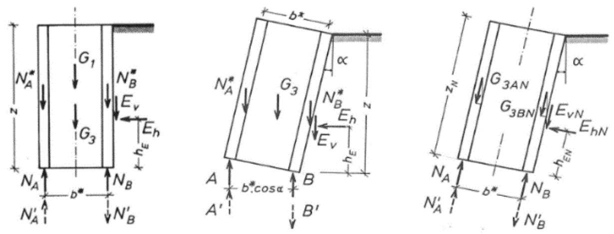
$$\bar{B} = G_{3B}$$

Tensile force at the earth side crib element due to horizontal component of earth pressure will be calculated as:

$$B' = \frac{E_h}{b^* \cos\alpha} \left(h_E - b^* \sin\alpha\right) \quad (6)$$

The safety factor against the lifting up of crib elements at earth side will be given by:

$$F_{LC} = \frac{B}{B'} \quad (7)$$



(a) (b) (c)

Figs. 1. Illustration of the forces acting on vertical and inclined crib walls made from precast concrete elements [21]

b. Lifting up from the forces parallel to wall inclination (Fig. 1(c)). In this case, the forces are resolved in parallel and normal direction to the wall inclination and the forces at the joint are calculated as:

$$N_B = k_B j G_{1N} + G_{3B,N} + E_{VN} \quad (8)$$

$$G_{1N} = ab\gamma / \cos\alpha$$

and:

$$G_{3B,N} = \frac{\bar{B}}{\cos\alpha}$$

$$N'_B = E_h \times \cos(90-\alpha) \frac{h_E}{\cos\alpha} \frac{1}{b^*} \quad (9)$$

The safety against uplifting will be given by:

$$F_{LC} = \frac{N_B}{N'_B} \quad (10)$$

In the above equation, $k_B \geq 0.5$ and $j \leq 1$ and for practical purpose, $k_B\, j$ can be assumed as 0.5 [21]. For each of these cases a global factor of safety of 1.5 will be required.

According to monolithic theory, the maximum compression at the outer side of crossing point is given by:

$$N_{A,B} = a' N \left(0{,}5 \pm \frac{e}{b'}\right) \quad (11)$$

The safety factor against the breaking of joints will be given by:

$$F_{CJ,A} = \frac{N_{A\ break}}{N_{A}\ available} \quad (12)$$

$$F_{CJ,B} = \frac{N_{B\ break}}{N_{B}\ available} \quad (13)$$

The example of cribwall models as shown in Fig. 2, Fig. 3 and Fig. 4.

Fig. 2. Wooden log crib wall for noise control in Lower Austria [4]

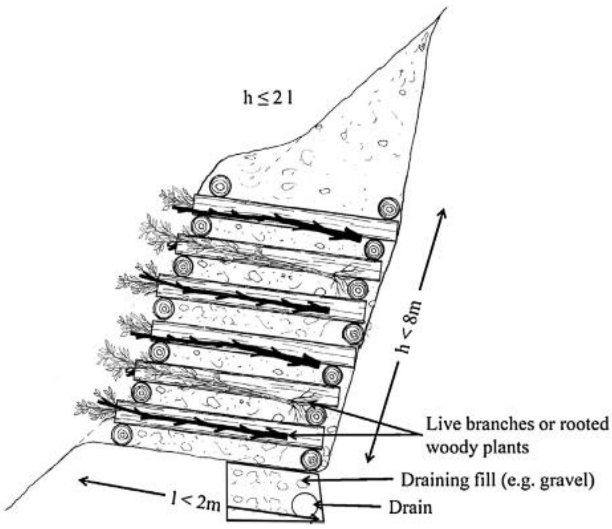


Fig. 3. Double log crib wall with drainage[5]

II.2. Three-Dimension of Limit Equilibrium Analysis

Three-dimensional slope stability analysis are extension of general 2-D limit equilibrium method [23]-[24]. The basic definition of these inter-column force functions was similar to that proposed by Morgenstern and Price [13].

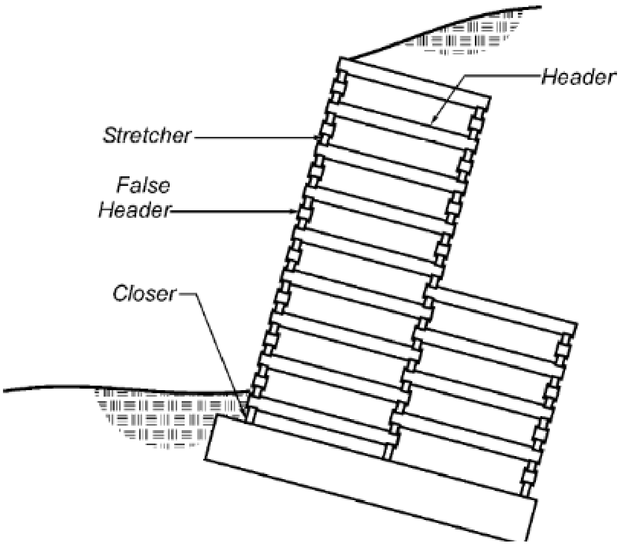


Fig. 4. Cross-section through a typical crib wall [6]

Slide3 2017 is a brand new 3-dimensional limit equilibrium method for slope stability program created by Rocscience. With Slide3 most of the analysis features found in our very popular 2D program Slide are now available in full 3D, including complex geology, anisotropic materials, loading, and support. Slide3 offers a wide variety of strength models for soil and rock, including Mohr-Coulomb, undrained, tremendous strength, anisotropic, generalized Hoek-Brown, SHANSEP, and more. These strength criteria allow the model all commonly encountered material types in slope stability analysis [20].

III. Research Method

The objects of the research were the road side slope in Muara Bone Village (Bone Subdistrict) and Oluhuta Village (Kabila Bone Subdistrict), Bone Bolango Regency. The samples of soil/rock were the undisturbed and disturbed sample that obtained on the dry season.

The crib walls used local materials, namely timber (coconut woods). The physical and mechanical properties of the soil/rock and timber discovered based on the laboratory test results were presented in Table I, Table II, and Table III.

TABLE I
THE PROPERTIES OF SOIL AND ROCK IN MUARA BONE VILLAGE

Parameters	Layer 1 (Silty sand)	Layer 2 (Volcanic Breccia)	Fill material
Water content, w (%)	29.4	0.81	0.61
Bulk unit weight, γ_b (kN/m^3)	14.82	25.42	25.30
Cohesion, c' (kN/m^2)	0	190.00	343.00
Angle of internal friction, φ' (^{o})	37.00	50.00	50.00
Young's modulus, E (kN/m^2)	890	9.26E+06	2,39E+07
Poisson's ratio, μ	0.35	0.25	0.28

The test carried by American Standard Test Materials (ASTM). The timber characteristics corrected again by SNI 7973-2013 [22]. In the case, used the load resistance factor design method. Data processing is analyzed using limit equilibrium method, i.e General Limit Equilibrium (GLE)/Morgenstern-Price Methods. Numerical analysis is done with the help of Slide3 2017 software. Shear strength parameters used in the analysis was the value of an effective cohesion (c') and the angle of effective internal friction (φ').

TABLE II
THE PROPERTIES OF SOIL AND ROCK IN OLUHUTA VILLAGE

Parameters	Layer 1 (Clayey sand)	Layer 2 (Andesite)	Fill material
Water content, w (%)	12.17	1.18	0.61
Bulk unit weight, γ_b (kN/m^3)	19.24	24.41	25.30
Cohesion, c' (kN/m^2)	12.95	520.00	343.00
Angle of internal friction, φ' (^{o})	30.00	53.00	50.00
Young's modulus, E (kN/m^2)	1,64E+04	1.23E+07	2,39E+07
Poisson's ratio,μ	0.15	0.30	0.28

TABLE III
THE PROPERTIES OF TIMBER

Parameters	Average Values
Moisture content, m (%)	15.13
Density, ρ (kN/m^3)	5.17
Compressive strength, $F_c'_{//}$ (kN/mm^2)	22.37
Shear Strength, $F_v'_{//}$ (kN/mm^2)	2.83
Young's modulus, E (kN/m^2)	10,549

IV. Result and Discussion

IV.1. *Numeric Simulation of The Natural Slope*

The analysis was conducted in Muara Bone and Oluhuta Village, Bone Bolango Regency. The slip surface described non-circular shape. The results of stability analysis and slope behavior in the locations are illustrated in Fig. 5 and Fig. 6.

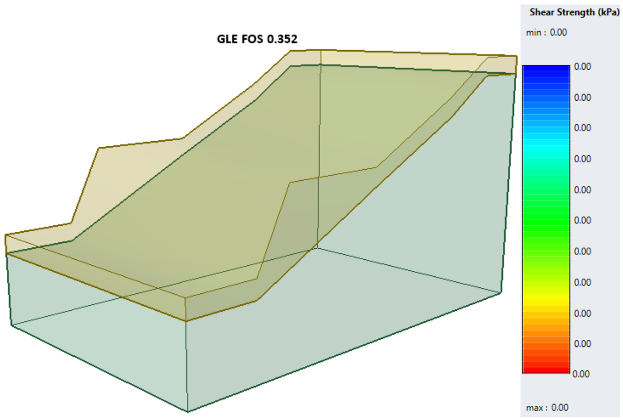


Fig. 5. Results of analysis of natural slope stability in Muara Bone Village

The results by GLE method show that the natural slopes in Muara Bone Village was unstable/critics (FS=0.35<1.5). The factor of safety (FS) in Oluhuta Village was 1.542. The condition of slope was stable, but during the rainy season (water content of clayey sand, w=20%), this slope was unstable, FS=1). Slope instability caused by geological conditions with slopes forming material have experienced weathering and the geometry of the slope is so steep. Moreover, triggered by rainfall is high enough to cause a reduction in shear strength and pore water pressure increase.

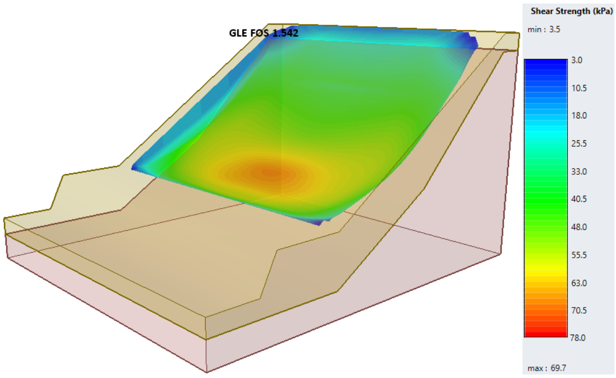


Fig. 6. Results of analysis of natural slope stability in Oluhuta Village

IV.2. Numeric Simulation of the Timber Crib Walls

The slope reinforcement design is done by using local materials i.e. timber/coconut wood (Fig. 7 and Fig. 8). The height of the crib wall, H=1.5-6.0 m, but in this analysis, the timber crib wall is designed with a height of 4 m.

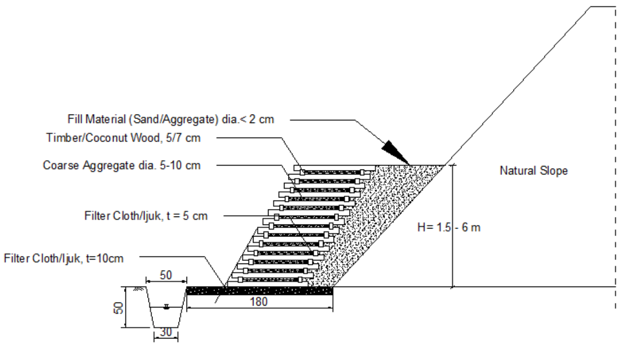


Fig. 7. Cross Section of timber crib walls

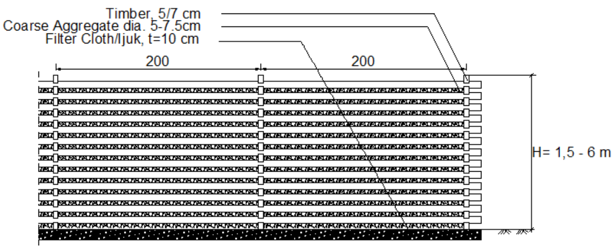


Fig. 8. Front side of timber crib wall

The analysis of sample was performed on one of the locations, the slope in Muara Bone Village, Bone Subistrict, with timber crib wall. The geometry of wall as shown in Fig. 9, with an average thickness of 0.23 m crib layer. The slope inclination (β)=0^o, the wall inclination angle (α=20^o from the vertical). The average of angle of internal friction, φ = 45^o, and the average of bulk unit weight, γ = 21.83 kN/m^3.

The angle of inclination of earth pressure (δ=2/3φ=30^o). The bearing capacity for gravel, σ_{permit}= 300 kN/m^2.

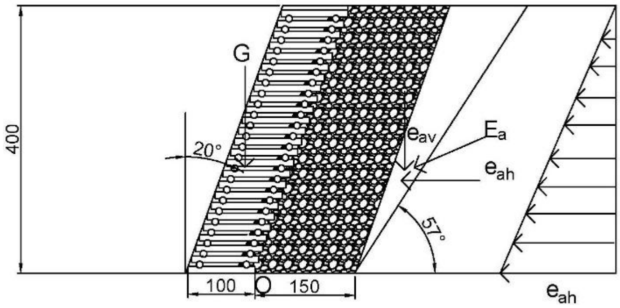


Fig. 9. The geometry and forces acting on the timber crib walls

1. Stability analysis of the external forces.

Based on the calculated by equations (1)-(4), the results of the external stability analysis for the timber crib walls as described in Table IV.

TABLE IV
THE RESULTS OF EXTERNAL STABILITY ANALYSIS
ON THE TIMBER CRIB WALLS

External Stability	Value
The total horizontal earth pressure acting on the wall surface, E_{ah} (kN/m)	10.48
The vertical component of earth pressure, E_{av} (kN)	1.85
The normal force due to self-weight of the soil and timber crib walls, N (kN)	91.6
The minimum pressure at the bottom soil, σ_1 (kN/m^2)	18.32
The maximum pressure at the bottom soil, σ_2 (kN/m^2)	164.88
Safety against of the bearing capacity failure, $\sigma_{permit}/\sigma_{max}$>1.5	1.87
Safety against the overturning, F_o> 1.5	1.76
Safety against sliding, F_s>1.5	4.92

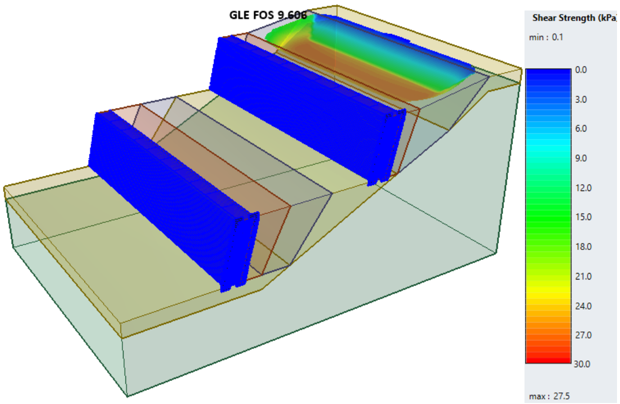
2. Stability analysis of the internal forces.

Based on the calculated by equation (5)-(13), the results of the external stability analysis for the timber crib walls as described in Table V.

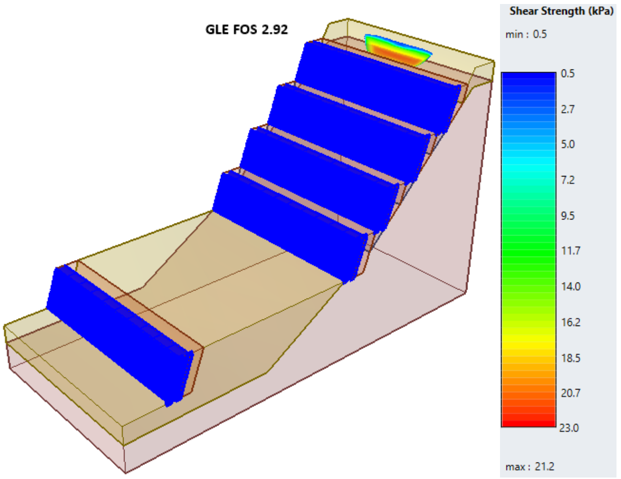
TABLE V
THE RESULTS OF INTERNAL STABILITY ANALYSIS
ON THE TIMBER CRIB WALLS

Internal Stability	Value
Safety against lifting force at earth side (from horizontal and vertical force), F_{LC}>1.5	4.26
Safety against lifting force at earth side (from force parallel to the slope of the wall), F_{LC}>1.5	7.78
Safety against the breaking of joint, $F_{CJ,A}$> 1.5	2.66
Safety against the breaking of joint, $F_{CJ,B}$> 1.5	1.54

The safety against the shear failure through crib walls by Slide3 2017 based on Morgenstern-Price/GLE Method) as shown in Figs. 10. The factor of safety (FS) after constructing timber crib wall increased to 9.6 in Muara Bone Village and 2.92 in Oluhuta Village.The timber crib wall has the safety factor greater than the safety factor of natural slope without reinforcement. The class quality of materials used in the crib wall reinforcement becomes one of the factors that affect the value of what is safe.



(a) Muara Bone Village (Bone Subdistrict)



(b) Oluhuta Village (Kabila Bone Subdistrict)

Figs. 10. Result of the analysis slope stability of timber crib walls

V. Conclusion

Based on the analysis done with the equilibrium limit method, the following conclusions have been drawn from this study:

1. Based on numerical simulation with the limit equilibrium method, the safety factor of natural slope in the research area illustrates that during the dry season, the slopes in Muara Bone was unstable *FS*=0.352. In Oluhuta Village, factor of safety in the dry season tends to be safe, which amounted to 1.542 but during the rainy season, the slopes in Oluhuta Village was unstable, *FS*=1.0.
2. The analysis of the crib walls describe the crib wall designs have safety factor that qualifies (*FS*>1.5), both external and internal stability. External stability analysis of the crib wall describe the value of the safety factor against bearing capacity failure, sliding and overtuning failure sequentially hazard was 1.85; 1.87; and 4.92. The results of the analysis of internal stability with the limit equilibrium method (by Slide 3D) represents the average value of a safety factoragainst shear failure of timber crib wall in Oluhuta Village, and Muara Bone Village sequentially were 2.91 and 9.78. The value of safety against lifting force of elements cribat earth side (from horizontal and vertical force), F_{LC} is 4.26. The value of safety against lifting force of elements cribat earth side (from the force parallel to the slope of the wall), F_{LC} is 7.78. The value of safety against the breaking of joint by monolithic theory are $F_{CJ,A}$=2.66, and $F_{CJ,B}$=1.54.
3. Crib wall with utilization expected this to be one of the alternatives in selecting the type of slope reinforcement in Bone Bolango Regency. Besides aiming for efficiency of construction costs, as well as to add aesthetic value.

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