Slope stability analysis of the drainage tunnel portal in Tanju Dam, Dompu District, West Nusa Tenggara

Edden Umaga Dinata[1], *I Gde Budi* Indrawan[1*], and *Arifudin* Idrus[1]

[1]Department of Geological Engineering, Faculty of Engineering, Universitas Gadjah Mada

Abstract. This paper presents design results of the tunnel portal slopes at the Tanju Dam, Dompu, West Nusa Tenggara. The objective of this research was to analyse the stability of the tunnel portal slopes using circular failure chart (CFC) method, limit equilibrium method (LEM), and finite element method (FEM). Input parameters were obtained from drill core evaluations and laboratory tests. By considering the rock mass rating (RMR) values of rock masses, which are categorized as class II, at the two slopes, adjustments for the cohesion and inner friction angle values are made. The inlet slope (IL) have cohesion values of 350 kPa and 40º inner friction angle and the outlet slope (OL) have cohesion values of 400 kPa and 45º inner friction angle. The CFC method shows that the IL and OL have safety factor (FS) values of 3.5 and 3.44, respectively. The LEM shows that the IL and OL have the FS values of 3.69 and 3.65, respectively. Meanwhile, the FEM shows that the IL and OL have FS values of 4.78 and 4.79, respectively. The stability analysis results indicate that designed slopes are stable.

1 Introduction

The study location is carried out at the drainage tunnel construction site of tanju dam. In Administrative, the tunnel is located in the village of Bara, Woja, Dompu District, West Nusa Tenggara Province (Fig. 1). Drainage is built to drain the drain 1.9 m3/sec water to fill Tanju reservoir. This research is purposed to determine the slope stability of the designed slope of the drainage tunnel in Tanju dam.

The research area is in morphology with hilly conditions around the tunnel which is a ridge that extends in a relatively northeast-southwest direction, with a ridge length of about 2.2 km and a peak elevation of 320 m [1]. The morphology around the location is quite steep with an angle of 45º – 60º .

Prediction and analysis of slope stability is a matter of concern for geotechnical engineers. This is due to the importance of slope stability analysis for planners to plan the slope of a slope in constructions such as dams, road tunnels and others.

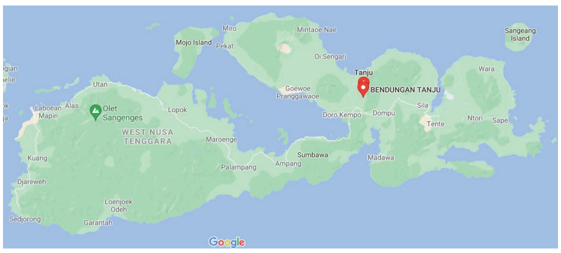

Fig. 1. Research location.

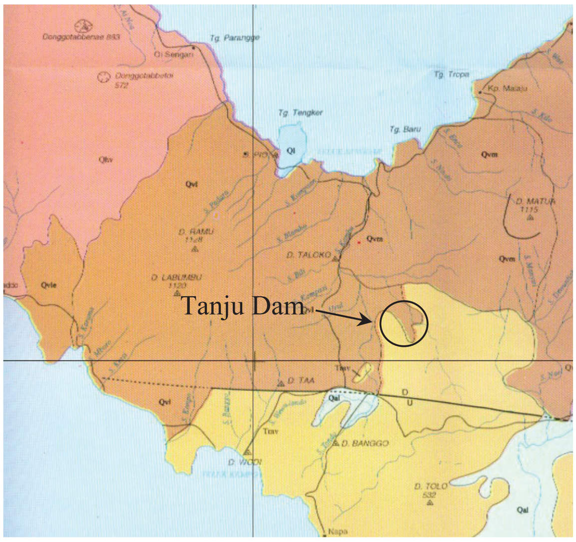

Fig. 2. Regional Geology Map of Sumbawa [2].

2 Geology condition

2.1 Regional geology

Based on the Regional Map (Fig. 2.), it shows that the research location is composed of old volcanic rock products (QTv, Qv) of Quaternary age and alluvial deposits [3]. This group consists of breccias lava and tuffs with a composition of andesite and basalt. The research location is mainly at the location of the planned tunnel which is composed of rocks that are even older

* Corresponding author: igbindrawan@ugm.ac.id.

than Tertiary and Quaternary. Tertiary rocks are predominantly composed of clastic volcanic sedimentary rocks, volcanic rocks and intrusions. Meanwhile, the quaternary rocks consist of volcanic sedimentary rocks, alluvial deposits and river sediments of the Resen age.

2.2 Geology structure

The hilly condition around the tunnel is a ridge that extends in a relatively northeast-southwest direction, with a ridge length of about 2.2 km and a peak elevation of 320 m. The morphology around the location is quite steep with an angle of 45º – 60º [1]

In general, the area around the Tanju Tunnel plan consists [4] of 5 (five) rock units, namely (Fig. 3.):
a. Coluvial
b. Weathered Andesite
c. Andesite
d. Weathered tuff breccia
e. Tuff Breccia

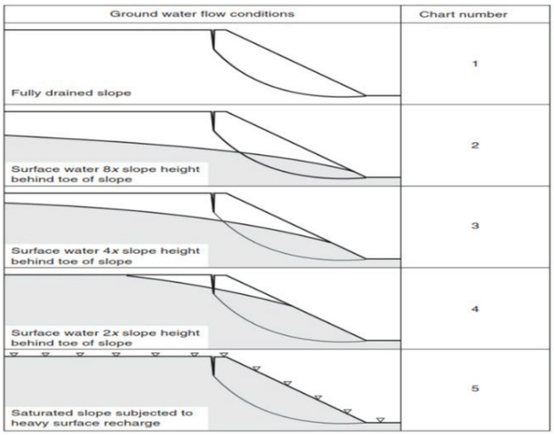

Fig. 3. Groundwater condition graphic (Duncan C. Wyllie & Christoper W. Mah, 2004) [4].

2.3 Rock mass rating

The RMR value [5] in this research area is 65 which can be classified as good rock as in the RMR [5] and GSI [5] classification tables (Table 1.), entered into the Type II Tunneling Support System. RMR value used only to determine the rock mass quality.

Table 1. RMR and the parameters [2].

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

1	Strenght of Intact Rock of Intact Rock	Point load strenght index	>10 Mpa	4-10 Mpa	2-4 Mpa	1-2 Mpa	For this Range - Uniaxial Compresive is prefered		
		Uniaxial Comp. Strenght	>250 Mpa	100-250 Mpa	50-100 Mpa	25-50 Mpa	5-25 Mpa	1-5 Mpa	< 1 Mpa
	Rating		15	12	7	4	2	1	0
2	RQD			90-100%	75-90%	50-75%	25-50%	<25%	
	Rating			20	17	13	8	3	
3	Spacing of Disc			>2m	0.5-2 m	20 - 60 cm	6 - 20 cm	< 6 cm	
	Rating			20	15	10	8	5	
4	Condition of Discontinuities		Very rough surface not continous no separation unweathered wall rock	Slightly rough surface separation < 1mm Slightly weathered walls	Slightly rough surface separation < 1mm Highly weathered walls	Slickersided surface or Gauge < 5mm thick or separation 1-5mm continous		Soft gauge >5mm thick or separation >5mm continous	
	Rating		30	25	20	10		0	
5	Groundwater			Completely dry	Damp	Wet	Dripping	Flowing	
				15	10	7	4	0	

B. RATINGS ADJUSMENT FOR DISCONTINUITY ORIENTATIONS

Strike and Dip Orientation		Very favourable	Favourable	Fair	Unfavourable	Very Favourable
Rating	Tunnels & Mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100-82	80-61	60-41	40-21	<21
Class Number	I	II	III	IV	V
Discription	Very Good Rock	Good Rock	Fair Rock	Poor Rock	Very Poor Rock

D. MEANING OF ROCK CLASSES

Class Number	I	II	III	IV	V
Average Stand-up time	20 years for 15m span	1 year for 10m span	1 week for 5m span	10hrs for 2.5 m span	30min for 1m span
Cohesion of rock mass (kpa)	>400	300-400	200-300	100-200	<100
Friction angle of rock mass (deg)	>45	35-45	25-35	15-25	<15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY CONDITION

Disc length	<1m	1-3m	3-10m	10-20m	>20m
Rating	6	4	2	1	0
Separation (Apeture)	none	<0.1mm	0.1-1mm	1-5mm	>5mm
Rating	6	5	4	1	0
Roughness	very rough	rough	slightly rough	smooth	slikensided
Rating	6	4	2	1	0
Infilling	none	Hard Filling <5mm	Hard filling >5mm	soft filling <5mm	soft filling >5mm
Rating	6	4	2	2	0
Weathering	Unweathered	Slightly Weathered	mod weathered	highly weat	Decomposed
Rating	6	5	3	1	0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION TUNNELING

<table>
<tr><td rowspan="8">Effect of disc to the tunnel</td><td colspan="5">Strike perpendicular to tunnel axis</td></tr>
<tr><td>drive with dip (dip 45-90)</td><td>Drive w/ dip (dip 20-45)</td><td colspan="2">Drive against dip (45-90)</td><td>Drive against dip 20-45</td></tr>
<tr><td>very favourable</td><td>Favourable</td><td colspan="2">Fair</td><td>Unfavourable</td></tr>
<tr><td>0</td><td>-2</td><td colspan="2">-5</td><td>-10</td></tr>
<tr><td colspan="5">Strike paralel to tunnel axis</td></tr>
<tr><td>Dip 20-45</td><td colspan="2">Dip 0-20</td><td colspan="2">Dip 45-90</td></tr>
<tr><td>Fair</td><td colspan="2">Fair</td><td colspan="2">Unfavourable</td></tr>
<tr><td>-5</td><td colspan="2">-5</td><td colspan="2">-10</td></tr>
</table>

3 Research method

3.1 Sample and parameters

The data used in this study include the geological structure on the slopes, geological mapping, core drill and laboratory test results. The samples that have been taken were carried out by laboratory tests [1] in the form of property index and engineering properties. The engineering properties parameter is obtained from the triaxial test so that the cohesion value and the inner shear angle are obtained.

3.2 Circular failure chart (CFC)

CFC charts are used to find the critical point of longitudinal and fracture surface tensions of various slope geometries and groundwater conditions [4]. This method is the easiest method to find the slope safety factor. This method is a semi-empirical method that requires minimal laboratory data such as material density, shear angle, cohesion, slope height and slope.

The CFC method is highly dependent on groundwater conditions. So that the analysis in this method is very dependent on determining field conditions. This can be seen in (Fig. 3). To determine the safety factor of the CFC method, you can follow the steps below (Fig. 4).

- The first step: determine the rock strength parameters that compose the slope.
- Second step: Use (Fig. 3) to determine groundwater conditions according to field conditions.
- The third step: Calculate the ratio value with the formula $c / (\gamma\ H \tan \varphi)$ and plot the calculation results in the CFC diagram that we use as shown in Fig. 5.
- Step four: Draw a straight line from the value in step three to the curved line that describes the amount of the angle of the slope.
- Step five: Use the following formula φ / FS or $c / (\gamma\ H\ FS)$ to find a convincing safety factor.

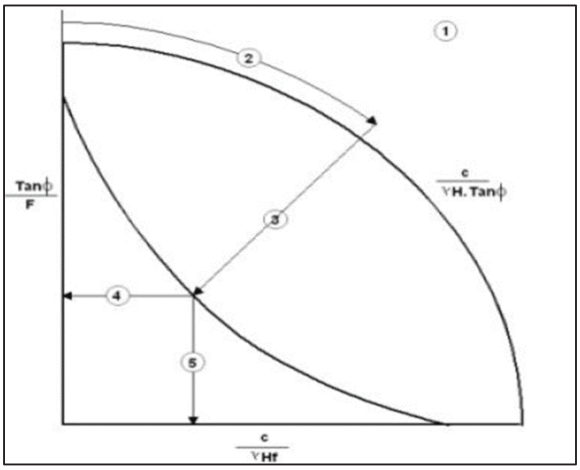

Fig. 4. Slope safety to CFC [5].

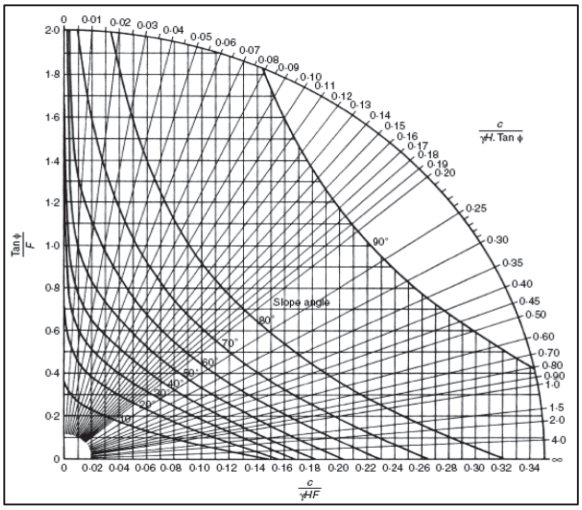

Fig. 5. CFC Model Graphic [5].

3.3 Finite element method (FEM)

The method of slope stability analysis used in this study is the finite element shear strength reduction technique (SSR-FEM). In this method, the available soil shear strength parameters are automatically reduced until failure occurs. So that the safe factor (SF) slope stability becomes:

$$\sum M_{sf} = \tan \phi_{input} / \tan \phi_{production} \quad (1)$$

$$= C_{input} / C_{production} \quad (2)$$

$$SF = \frac{current\ shear\ strength}{landslide\ shear\ strength} \quad (3)$$

$$= \text{Value of } \sum M_{sf} \text{ at time of landslide} \quad (4)$$

Note:
C_{input} = Soil Cohesion
ϕ_{input} = Ground shear angle (°)
$C_{reduction}$ = Reduction of Soil Cohesion
$\phi_{reduction}$ = Reduction of Ground shear angle (°)
(Duncan C. Wyllie & Christoper W. Mah,) [4]

3.4 Limited equlibrium method (LEM)

LEM is a method that uses the principle of force equilibrium. This method of analysis first assumes the area of failure that can occur. There are two assumptions of the landslide area [4], namely: the landslide plane is circular and the sliding plane is assumed to be non-circular (it can also be planar).

The calculation is carried out by dividing the land that is in the landslide plane into sections, therefore this method is also known as the method of slice. The various existing solutions for this wedge method have been developed over the years, from Fellenius, Taylor, Bishop, Morgenstern-Price to Sarma and others.

In this LEM the safety factor, SF, is in principle calculated from the ratio between the shear strength of the soil, τf with the thrust τ or the ratio between the moment of resistance, RM, to the moment of thrust, DM, as shown by the formula below.

$$SF = \frac{\tau f}{\tau}\ or\ SF = \frac{RM}{DM} \quad (5)$$

(Duncan C. Wyllie & Christoper W. Mah,) [4].

4 Results and discussion

The slopes at the inlet and outlet of the Tanju Tunnel conduit were analyzed using the CFC method. For each location analyzed, one sample was taken for laboratory analysis. Sampling was done using the rotary drilling method. Samples were taken at the Inlet (IL) and Outlet (OL) locations at a depth of 8 m. From the results of the field description, the naming of rocks is andesite. To find the safety value, the triaxialysis test was carried out to produce the cohesion value (c) and the inner shear angle (φ) according to ASTM D-2264. The groundwater condition in the field is also considered, as well as the condition of the rock mass.

4.1 Determine the safety factor of slope using cfc, lem, and fem method

By following the steps described in the previous sub-chapter, the authors used dry groundwater conditions (Fig. 3). So that the graph used is graph number 1 (Fig.5). This determination is adjusted to the conditions in the field where the slopes at the two research locations show dry conditions. *Rocscience slide V 6.0* used to calculate LEM and *Rocscience slide V 8.0* used to calculate FEM.

4.1.1. Inlet slope

The inlet slope condition has a geometry of 12 meters high and a slope of 45 degree. From the results of the drilling investigation, the RMR value of rock which is included in the good rock class II class is obtained. With laboratory data can be seen in (able 2). In determining the safety factor, the rock engineering parameters used are adjusted to the rock mass condition or RMR.

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So the authors use a cohesion value of 350 kPa and an inner shear angle of 40º. refers to (Table 1).
From the calculation using the formula c / (γ H tan φ), the result is 1.4. So that a line or plot is drawn on the CFC graph, it can be found tan φ / FS = 0.28
Then: tan φ / FS = 0.28
tan 40 / 0.28 = FS
FS = 3.5

From these calculations, it is obtained SF of 3.5 which is indicated that the slope is stable.

From the calculation of stability using the LEM (Bishop) method with the help of the Rocscience slide V 6.0 program and the Mohr-Colomb collapse parameter, it was found that an SF of 3.69 was included in the safe category, which can be seen in (Fig. 6).

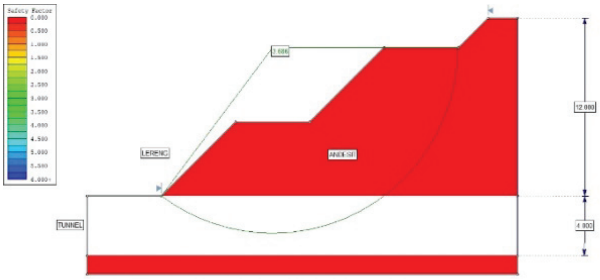

Fig. 6. Inlet slope Safety Factor as the result of LEM Calculation using Bishop Method

From the calculation of stability using the FEM method with the help of the Rocscience Phase V 8.0 program and the Mohr-Colomb collapse parameter, it is found that an SF of 4.78 is included in the safe category, which can be seen in (Fig. 7).

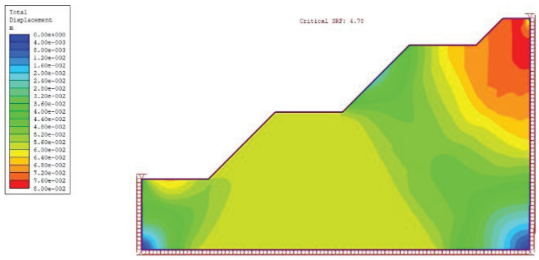

Fig. 7. Inlet slope Safety Factor as the result of FEM Calculation.

4.1.2. Outlet slope

The condition of the outlet slope has a geometry of 12 meters high and a slope of 45. From the results of the drilling investigation, the RMR value of rock is included in the good rock class II. With laboratory data can be seen in (Table 2). In determining the safety factor, the rock engineering parameters used are adjusted to the rock mass condition or RMR.

Table 2. Laboratorium results [1].

SUMMARY OF ROCK TEST					
PROJECT				**D/D TEROWONGAN N TANJU**	
SAMPLE NO				**INLET**	**OUTLET**
DEPTH			M	8-8,7	7-7,7
I	**SPECIFIC GRAVITY & ABSORPTION**				
	Bulk Dry Basis			2.562	2.607
	Saturated Surface Dry Condition			2.595	2.625
	Apparent			2.650	2.656
	Absorption		(%)	1.28	0.72
II	**SPECIFIC GRAVITY OF SOIL**			-	-
III	**NATURAL DENSITY**		**gr/cm³**	2.553	2.614
IV	**WATER CONTENT**		**%**	1.04	0.30
V	**DRY DENSITY**		**gr/cm³**	2.526	2.606
VI	**VOID RATIO**			0.049	0.019
VII	**SATURA TED DENSITY**			2.573	2.625
VIII	**SUBMERGED DENSITY**			1.573	1.625
IX	**DEGREE OF SATURATION**			56.39	41.53
X	**UNIAXIAL COMPRESSIVE STRENGTH**				
	Comp. Strenght qu		kg/cm²	357.34	610.20
	Modulus Elasticity	Axial Ea	kg/cm²	4,216E + 04	7,540E +04
		Diametral Ed	kg/cm²	1,044E + 05	1.735E + 05
	Poisson's Rasio μ		-	0.404	0.435
	Axial Strain		%	0.87	0.84

So the authors use a cohesion value of 400 kPa and an inner shear angle of 45°. refers to (Table 1).
From the calculation using the formula c / (γ H tan φ), the result is 1.4. So that a line or plot is drawn on the CFC graph, the obtained tan φ / FS = 0.29
Then: tan φ / FS = 0.29
tan 45 / 0.29 = FS
FS = 3.44

From these calculations, it is found that SF is 3.44 which is included in the safe category.

From the calculation of stability using the LEM (Bishop) method with the help of the Rocscience slide V 6.0 program and the Mohr-Colomb collapse parameter, the SF of 3.65 can be seen (Fig. 8).

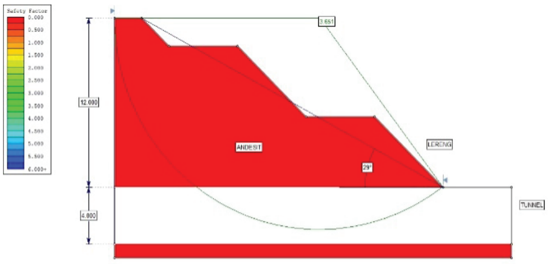

Fig. 8. Outlet slope Safety Factor as the result of LEM Calculation using bishop method.

From the calculation of stability using the FEM method with the help of the Rocscience Phase V 8.0 program and the Mohr-Colomb collapse parameter, it was found that an SF of 4.79 was included in the safe category, which can be seen in (Fig. 9).

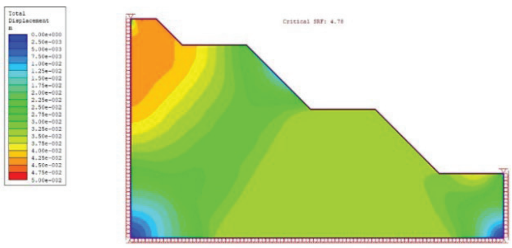

Fig. 9. Outlet slope Safety Factor as the result of FEM Calculation.

5 Conclusion and recommendations

Based on the field conditions, the slopes in the research location are categorized as dry, so the number 1 graph model is used in the CFC method. On the inlet slope (IL), laboratory results show the density value of 2.526 g/ cm^3 or 24.77 kN / m^3, cohesion of 25.4 kg / cm^3 or 2451.66 kPa and the inner angle of shear of 46°. On the outlet slope (OL), from laboratory results, the density value is 2.606 g/ cm^3 or 25.60 kN / m^3, cohesion is 37.846 kg / cm^3 or 3711.42 kPa and the inner shear angle is 54°. By considering the RMR conditions of the two slopes that are included in the class 2 category, adjustments for the cohesion value and inner shear angle are made according to (Table 1).

From the calculation of the CFC value, the safety factor value is 3.5 on the inlet slope (IL) and 3.44 on the outlet slope (OL), both of which are included in safe conditions. From the calculation of the LEM value, the value of the safety factor is 3.69 on the inlet slope (IL) and 3.65 on the outlet slope (OL), both of which are in a safe condition. From the calculation of the FEM value, the safety factor value is 4.78 on the inlet slope (IL) and 4.79 on the outlet slope (OL), both of which are in a safe condition. From the calculation of CFC, LEM, and FEM can be value the slope stability of the designed drainage tunnel is in safe condition

Research can be strengthened by various methods such as the slope mass rating (SMR) to determine the type of reinforcement and protection.

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