Analysis of slope stability based in the spencer method on the ring road section, Sikumana. Kupang City

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Abstract. The analysis of slope stability is one of the most common solutions that are used to answer any problems about landslides. In applying it, how to know the parameters that are always used in the analysis of slope stability is the key way to calculate it in detail. The parameters like slope dimensions, soil samples (disturb and undisturb), and laboratory test. In this case, the slope stability is used Spencer’s Method as a limit equilibrium method, and in another word a merge method of moment equilibrium (Bishop’s Method) and force equilibrium (Janbu’s Method). The soil samples are taken from the long of slope surface for 3 points, above, in the middle, and the bellow. On laboratory test we have to get the parameters like cohesi (c), friction angle (ϕ), and unit weight (γ). This analysis is to know the safety factor (SF) value from the slope at 40 road. From the research, the slope is made of homogenous soil, clay from the noele formation. And we can get the material properties for the samples according, unit weight: 16.80 kN/m^3, cohesi (c): 4.88 kPa, friction angle (ϕ): 39.32° (first sample); unit weight (γ): 15.97 kN/m^3, Cohesi (c): 5.08 kPa, friction angle (ϕ): 26.20° (second sample); unit weight (γ): 15.48 kN/m^3, cohesi (c): 5.28 kPa, friction angle (ϕ): 26.20°. And the FoS value is 0.548 based on Spencer’s Method calculated. So, it is made some slope design recommendations to get the stability condition of the slope (SF>1), are SF1=1.610; SF2=1.410.

1. Introduction
The slope of the slope with various items that influence each other for each value contained in it is a framework that forms the geometry of the slope and determines the level of safety or stability of a slope, whether for slopes or artificial slopes where the possibility of a landslide or landslide value will always exist, need to be known to see the danger of landslides [1].

As in the above discussion, on top of planning landslides at times on a slope, the geometric conditions of the slopes seen on Jalan Jalur 40, Kupang, are very worrying, because in plain view, landslides are very easy to occur in the area, because the composition of silt at any time will be very easily eroded and subjected to weathering.

1.1 Research purposes
Basically, the research aims to answer any problems raised in the problem formulation section above, which should clarify the direction of the discussion later as part of the general description. In the context of research on slope stability on Jalan Jalur 40, it aims to determine the FK value for the original existing
slope based on the results of the Spencer Method analysis from laboratory data and suppose to design slope recommendations that will be applied to slope making.

1.2. Scope of problem
- The research was conducted on Jalan Jalur 40 with a random sampling method at 3 points on the front of the slope or sampling method
- Analysis using the Spencer Method on Rocscience Slide V6.0 Software to determine the FK value of slopes
- Does not discuss the existence of midwives.

1.3. Benefits of research
- For the Department of Mining Engineering, Nusa Cendana University
- This research is a good input for the department so that it is the first step to prevent the possibility of landslides along Jalan Jalur 40
- For Local Government
- This research can be a reference for the local government to pay attention to the condition of the slopes along Jalan Jalur 40, so that it can prevent the possibility of landslides early and as soon as possible to design a more stable slope geometry by building cooperation with related parties.

2. Map of location away
The research location is located at the Laboratory of the Public Works Office of East Nusa Tenggara Province, while the soil sampling is on Jalan Jalur 40, Kupang City, East Nusa Tenggara to be precise at coordinates -100 13’36,28884 ”- 1230 34’3,64404” BT.

3. Theoretical basis

3.1. Slope stability
Landslides and anything related to it due to changes in land mass we have very often encountered in everyday life which on the one hand is a serious problem with a million long-term impacts or losses. This stability is very much determined by a large number of landslide fields, so mathematically it can be predicted as instability that occurs naturally and in the process the slope capacity is reviewed in more detail.

3.2. Factors affecting slope stability
Spread of rock
- Geological structure
- Morphology
- Climate
- Degree of weathering
- Human Work
- Slope geometry

3.3. Landslides and their types
In general, landslides are defined as the displacement of slope-forming material in the form of rock, rubble, soil or mixed materials moving down or out of the slope due to the influence of the force of gravity.
Types of landslides

3.3.1. Translation avalanche

3.3.2. Rock crash

3.3.3. Rotational avalanches

3.3.4. Block movement

Figure 1. translation avalanche.

Figure 2. Rotational avalanche.

Figure 3. Longsoran blok

Figure 4. Rock rubble
3.3.5.  Ground termites

![Ground termites](image)

**Figure 6.** soil crawl.

3.3.6.  Substitution flow

![Substitution flow](image)

**Figure 7.** Substitution flow.

Soil physical properties

3.3.7.  Optimum moisture content

\[
w = \frac{Ww}{Ws} x
\]

Information:
- \( w \) = water content (\%)
- \( Ww \) = water weight (gr)
- \( Ws \) = dry sample soil weight (gr)

3.3.8.  Specific gravity

\[
Gs = \frac{Wt}{(W5 - W3)}
\]

Where:
- \( Gs \) = specific gravity
- \( Wt \) = sample weight (gr)
- \( W3 \) = weight of pinometer + water + sample (gr)
- \( W5 \) = (weight of pinometer + sample) - (weight of pinometer) + (weight of pinometer + water) (gr)
3.3.9. Permeability

\[ k = 0.025 \frac{L}{t} \log \frac{h_1}{h_2} \]

Where:
- \( k \) = permeability coefficient (cm / s)
- \( L \) = sample length or height (cm)
- \( t \) = time of observation (s)
- \( h_1 \) = initial head height (cm)
- \( h_2 \) = final head height (cm)

3.4. Soil mechanics

3.4.1. Direct shear test

![Shear stress and normal stress](image)

**Figure 8.** Shear stress and normal stress.

3.4.2. Safety factor

\[ sf = \frac{\text{resisting force}}{\text{driving force of landslide}} \]

Calculation Method safety factor Mohr Coulomb and Metode Spencer

3.5. Bishop method

![Styless working on the bishop method wedge](image)

**Figure 9.** Styles working on the bishop method wedge.
$$SF = \frac{\sum [c \cdot b + (W - b \cdot u) \tan \phi']}{\cos \alpha (1 + \tan \phi \cdot \tan \alpha / F)} \frac{1}{\sum W \sin \alpha}$$

3.6. Jandu method

![Figure 10. Styles acting on the slice of the janbu method.](image)

$$SF: \frac{\sum [c \cdot b + (W - b \cdot u) \tan \phi']}{\cos \alpha (1 + \tan \phi \cdot \tan \alpha / F)} \frac{1}{\sum W \tan \alpha}$$

3.7. Spencer method

$$\frac{X}{E} = \text{konstan} = \tan \phi = \lambda$$

For the derivative of the vertical equilibrium formula, it is still the same as the method bishop and janbu,

$$(P - uI) = \frac{W - t\left[\frac{c \cdot \sin \alpha}{F}\right] + u \cdot \cos \alpha}{\cos \alpha + \sin \alpha \cdot \frac{\tan \phi}{F}}$$

SF Bishop

$$SF = \frac{\sum [c \cdot b + (W - b \cdot u) \tan \phi']}{\cos \alpha (1 + \tan \phi \cdot \tan \alpha / F)} \frac{1}{\sum W \sin \alpha}$$

Sf Janbu

$$Sf: \frac{\sum [c \cdot b + (W - b \cdot u) \tan \phi']}{\cos \alpha (1 + \tan \phi \cdot \tan \alpha / F)} \frac{1}{\sum W \tan \alpha}$$
Figure 1. an example of the intersection of Fm and Ff as FK Spencer.

4. Research methodology
Research flow chart

Figure 12. Research flowchart.

5. Discussion

5.1. Soil physical properties testing

5.1.1. Water content
- Top samples
Table 1. Upper sample compaction.

| No. | Test                  | Unit      | 200 ml | 250 ml | 300 ml | 350 ml | 400 ml |
|-----|-----------------------|-----------|--------|--------|--------|--------|--------|
| 1   | Water Content (w)     | %         | 5,499  | 11,245 | 15,937 | 17,159 | 18,444 |
| 2   | Wet Weight (Yb)       | gr/cm³    | 1.368  | 1.471  | 1.550  | 1.561  | 1.794  |
| 3   | Dry Weight (Yd)       | gr/cm³    | 1.297  | 1.323  | 1.343  | 1.332  | 1.313  |
| 4   | Soil Density Line     |           | 1.818  | 1.988  | 1.816  | 1.777  | 1.740  |
| 5   | Porosity (n)          | %         | 86,545 | 79,171 | 74,737 | 77,330 | 81,179 |
| 6   | Degrees of Distance (Sr) | %      | 4,701  | 7,574  | 13,754 | 12,877 | 10,948 |

Midle samples

Table 2. Middle sample compaction.

| No. | Test                  | Unit      | 200 ml | 250 ml | 300 ml | 350 ml | 400 ml |
|-----|-----------------------|-----------|--------|--------|--------|--------|--------|
| 1   | Water Content (w)     | %         | 9,8    | 12,50  | 13,578 | 17,068 | 19,00  |
| 2   | Wet Weight (Yb)       | gr/cm³    | 1.444  | 1.504  | 1.570  | 1.592  | 1.571  |
| 3   | Dry Weight (Yd)       | gr/cm³    | 1.352  | 1.360  | 1.382  | 1.360  | 1.320  |
| 4   | Soil Density Line     |           | 2.071  | 1.973  | 1.813  | 1.780  | 1.745  |
| 5   | Porosity (n)          | %         | 75,550 | 80,308 | 80,965 | 79,570 | 78,209 |
| 6   | Degrees of Distance (Sr) | %      | 8,362  | 8,00   | 10,11  | 11,438 | 13,554 |

Bottom Sample

Table 3. Table lower sample compaction.

| No. | Test                  | Unit      | 200 ml | 250 ml | 300 ml | 350 ml | 400 ml |
|-----|-----------------------|-----------|--------|--------|--------|--------|--------|
| 1   | Water Content (w)     | %         | 11,513 | 12,281 | 18,865 | 22,679 | 27,961 |
| 2   | Wet Weight (Yb)       | gr/cm³    | 11,443 | 1,466  | 1,578  | 1,592  | 1,614  |
| 3   | Dry Weight (Yd)       | gr/cm³    | 1,294  | 1,306  | 1,328  | 1,298  | 1,261  |
| 4   | Soil Density Line     |           | 1,983  | 1,953  | 1,730  | 1,624  | 1,494  |
| 5   | Porosity (n)          | %         | 74,665 | 73,877 | 68,420 | 72,628 | 74,664 |
| 6   | Degrees of Distance (Sr) | %      | 10,038 | 11,042 | 22,379 | 21,967 | 24,378 |

5.1.2. Specific gravity

Top Sample

Table 4. Density testing of specific gravity.

| Test                          | Calculation | difference test |
|-------------------------------|-------------|-----------------|
| No. Picnometer                | A           | B               |
| Pictometer Weight + Example (gr) | W2         | 79.10           | 76.27          |
| Pictometer Weight (gr)        | W1          | 65.69           | 62.22          |
| Soil Weight (gr)              | Wt=W2-W1    | 13.41           | 14.05          |
| Heating Temperature (°C)      |             | 150°C           |                |
| Picno weight. + Water + Soil at 25°C | W3     | 174.52          | 174.54         |
| Picnometer Weight + Water at 25°C | W4      | 165.98          | 166.42         |
| W5=Wt+W4 (Gr)                 |             | 179.39          | 180.47         |
| Fill Soil (cm³)               |             | 4.87            | 5.93           |
| Density (gr/cm³)              |             | 2.753           | 5.93           |
| Average Density               | (Gs_a + Gs_b)/2 | 2.561          |                |
Table 5. Middle sample density testing.

| Test                               | Calculation | difference test |
|------------------------------------|-------------|-----------------|
| No. Picnometer                     | C           | D               |
| Pictometer Weight + Example (gr)   | W2          | 75.30           | 77.31           |
| Pictometer Weight (gr)             | W1          | 65.57           | 63.31           |
| Soil Weight (gr)                   | Wt=W2-W1    | 12.73           | 14              |
| Heating Temperature (°C)           |             | 150°C           |                 |
| Picno weight. + Water + Soil at 25°C | W3          | 177.00           | 182.21           |
| Picnometer Weight + Water at 25°C  | W4          | 169.19           | 173.53           |
| W5=Wt+W4 (Gr)                      |             | 181.92           | 187.53           |
| Fill Soil (cm³)                    | W5-W3       | 4.92             | 5.32             |
| Density (gr/cm³)                   | Wt(W5-W3)   | 2.587            | 2.632            |
| Average Density                    | (Gs_a + Gs_b)/2 | 2.609           |                 |

• Bottom Sample

Table 6. Lower sample density testing.

| Test                               | Calculation | difference test |
|------------------------------------|-------------|-----------------|
| No. Picnometer                     | E           | F               |
| Pictometer Weight + Example (gr)   | W2          | 52.35           | 50.82           |
| Pictometer Weight (gr)             | W1          | 38.44           | 36.77           |
| Soil Weight (gr)                   | Wt=W2-W1    | 13.91           | 14.05           |
| Heating Temperature (°C)           |             | 150°C           |                 |
| Picno weight. + Water + Soil at 25°C | W3          | 146.46           | 145.30           |
| Picnometer Weight + Water at 25°C  | W4          | 137.43           | 137.40           |
| W5=Wt+W4 (Gr)                      |             | 151.34           | 151.45           |
| Fill Soil (cm³)                    | W5-W3       | 4.88             | 6.15             |
| Density (gr/cm³)                   | Wt(W5-W3)   | 2.850            | 2.285            |
| Average Density                    | (Gs_a + Gs_b)/2 | 2.5675          |                 |

5.1.3. Permeability

• Top Sample

Table 7. Upper sample permeability coefficient value.

| h1 (cm) | h2 (cm) | h1/h2 | Log (h1/h2) | L/t | T (s) | T(°C) | K(cm/s) |
|---------|---------|-------|-------------|-----|-------|-------|---------|
| 100     | 94.4    | 1.06  | 0.025       | 0.01| 300   | 25°   | 6.25 x 10⁻⁶ |
| 94.2    | 88.4    | 1.07  | 0.029       | 0.01| 300   | 25°   | 7.25 x 10⁻⁶ |
| 88.4    | 82.6    | 1.07  | 0.029       | 0.01| 300   | 25°   | 7.25 x 10⁻⁶ |
Middle sample

**Table 8.** Value of middle sample permeability coefficient.

| h1 (cm) | h2 (cm) | h1/h2 | Log (h1/h2) | L/t | T (s) | T(°C) | K(cm/s) |
|---------|---------|-------|-------------|-----|-------|-------|---------|
| 100     | 94.8    | 1.06  | 0.025       | 0.01| 300   | 25°   | 6.25 x 10⁻⁶ |
| 94.8    | 89.6    | 1.06  | 0.025       | 0.01| 300   | 25°   | 6.25 x 10⁻⁶ |
| 89.6    | 84.4    | 1.06  | 0.025       | 0.01| 300   | 25°   | 6.25 x 10⁻⁶ |

Bottom Sample

**Table 9.** the value of the lower sample permeability coefficient.

| h1 (cm) | h2 (cm) | h1/h2 | Log (h1/h2) | L/t | T (s) | T(°C) | K(cm/s) |
|---------|---------|-------|-------------|-----|-------|-------|---------|
| 100     | 94      | 1.06  | 0.025       | 0.01| 300   | 25°   | 6.25 x 10⁻⁶ |
| 94      | 88      | 1.06  | 0.025       | 0.01| 300   | 25°   | 6.25 x 10⁻⁶ |
| 88      | 82      | 1.06  | 0.025       | 0.01| 300   | 25°   | 6.25 x 10⁻⁶ |

5.2. **Slope geometry profile**

The slope profile or slope geometry at the research location which is located on Jalan Jalur 40 consists of 1 level or single bench:
Slope width: 9.08 m
Slope height: 8.76 m
Slope angle: 84°
Level height: 12 m

5.2.1. **Test results for direct shear strength and compaction of Upper Sample:**

- Weight (γ): 16.80 kN / m³
- Cohesion (c): 4.88 kPa
- Inner sliding angle (ϕ): 39.32°

5.2.2. **Test results for direct shear strength and compaction of Middle Sample:**

- Load weight (γ): 15.97 kN / m³
- Cohesion (c): 5.08 kPa
- Inner sliding angle (ϕ): 26.200

5.2.3. **Test results for direct shear strength and compaction of the Lower Sample:**

- Load weight (γ): 15.48 kN / m³
- Cohesion (c): 5.28 kPa
- Inner sliding angle (ϕ): 26.200
Due to the unstable slope conditions, it is necessary to redesign the slope's geography until it reaches a stable state.

5.3. Recommended SF for stable slopes

5.3.1. Recommended Stable Slopes 1
Slope height: 8.76 m
Level height: 4.08 m
Level width1: 7.35 m
Level width2: 5.00 m
Inclined plane length: 5.48 m
Slope angle: 440°

5.3.2. Recommended stable slopes 2
Slope height: 8.76 m
Level height: 8.16 m
Level width1: 7.35 m
Inclined plane length: 15.58 m

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**Figure 13.** FK slide calculation results $= 0.588$.

**Figure 14.** $sf = 1,610$. 
Conclusions and suggestions

Based on the results of laboratory testing and analysis of the physical and mechanical properties of the soil on the slope-forming material carried out at the research location, the following conclusions can be drawn:

6.1. Slope geometry profile
The slope profile or slope geometry at the research location which is located on Jalan Jalur 40 consists of 1 level or single bench:

Slope width: 9.08 m
Slope height: 8.76 m
Slope angle: 840°
Level height: 12 m

6.2. Physical and mechanical properties of the slope area of the study location

6.2.1. Top Sample
The physical characteristics of the sample at the research location are

- Moisture content: 11.28%
- Dry Fill Weight: 1.297 g / cm³
- Specific Gravity: 2.561 gr / cm³
- Permeability: 6.25 x 10^-6 cm / s

6.2.2. Middle Sample
The physical characteristics of the middle sample at the research location are

- Moisture Content: 11.11%
- Dry Fill Weight: 1.315 g / cm³
- Specific Gravity: 2.609 gr / cm³
- Permeability: 6.25 x 10^-6 cm / s
The mechanical properties of the middle sample at the research location are
- Content Weight: 15.97 kN / m³
- Cohesion: 5.08 kPa
- Inner Slide Angle: 26,200

6.2.3. Bottom samples
- The physical characteristics of the lower sample at the research location are
  - Moisture content: 11.11%
  - Dry Fill Weight: 1.294 g / cm³
  - Specific Gravity: 2.5675 gr / cm³
  - Permeability: 6.25 x 10⁻⁶ cm / s
- The mechanical properties of the lower sample at the research location are
  - Content Weight: 15.48 kN / m³
  - Cohesion: 5.28 kPa
  - Inner Slide Angle: 26,200

6.3. Recommended Stable Slopes 2
- SF : 1.621

6.4. Recommended Stable Slopes 3
- SF : 1.415

6.5. Suggestion
- Regular or continuous monitoring of existing slope conditions, especially slopes along the road, so as to minimize the occurrence of landslides at any time
- Efforts that can be made to prevent landslides on slopes are to design the geometry of the slope levels to reach conditions that can be categorized as stable with SF > 1.0.

References
[1] Lopa R T, Arham and B Bakri 2017 Pengaruh Hubungan Intensitas Curah Hujan Dan Kemiringan Lahan Terhadap Laju Erosi Jurnal analisis kestabilan lereng 2019