Environmental Aspect in Infrastructure Planning Using Starlet-Perdana Model

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Abstract. Starlet-Perdana stands for Stabilisasi & Rancangbangun Lereng Terpadu – Perkuatan Dayadukung Tana (Stabilization & Design Integration of Slope – Strengthening of Soil Bearing Capacity). The research is carried out in the northern parts of Bandung Basin at Cilengkrang and Jatinangor areas, around the foot of Gunung Manglayang and Jatinangor. The soil and rock materials are from weathered volcanic rocks. Areas that have been identified as landslide-prone are required some geotechnical engineering as well as direction in environmental management and monitoring. This paper presents a model of slope stability and soil bearing capacity to support infrastructure planning. This paper explains the relationship of slope with Factor of Safety (FS), application of Starlet model, soil bearing capacity, and improvement of expansive soil. The research activity began with a literature study, field survey as well as data collection, field analysis and laboratory analysis of soil / rock mechanics, delineation of landslide-prone areas, analysis of the relationship between slope and Factor of Safety (FS), calculation of soil bearing capacity, map data processing. Infrastructure planning needs to have a strong and long-term element, so the direction of the environmental management and monitoring is required as one of the efforts in environmental feasibility studies.

1. Introduction

1.1. Background
Regional development and infrastructure development have certain criteria [1], [2]. Assessment for regional development factors include slope, area stability, and rock characteristic (including descriptions of prone-to-ground-shaking rocks related to foundations and deformations), physical and mechanical properties of materials (clay, sand, breccia, igneous rock, swelling clay, shrinkage clay, expansive soil), difficulty level of foundation, threat of geological disasters (ground motion, foundation failure, etc.), and geological weaknesses. Common problems with sloping land are slope stability and soil bearing capacity for foundations. Another problem is the presence of expansive soil. These problems are related to infrastructure and environment. Infrastructure encompasses: a) Building foundations (shallow foundations and deep foundations, for the purposes of bridges, houses and
buildings with one or more floors, including the foundation of the airstrip, etc.); b) Engineering slopes (slope resulted from cut & fill work, cuts and slope dumps, trenches, or terraces); c) Retaining wall (gabion).

In regional and infrastructure development, geotechnical studies are required along with geological engineering studies. Aspects of the study that lead to infrastructure in a site scale, can be approached through geotechnics and geomechanics. For examples: a study of slope stability analysis, soil support for foundations, tunnel planning, etc. Geotechnics are useful for achieving the success of physical development of infrastructure that is strong and safe from the threat of damage. A broader aspect for studying the potential and constraint of the region can be approached by engineering geology. Another important role is the environmental management and monitoring of the infrastructure. Direction of environmental management and monitoring is to maintain the environment to remain stable and safe after the infrastructure is built.

The best environmental management is based on technical feasibility studies or detailed geological studies which include the study of engineering geology, geotechnics, geomechanics and hydrogeology. Environmental impacts that must be managed include: types of impacts, sources of impacts, impacts that arise, management of impacts. Direction of environmental monitoring is required to understand factors that need to be monitored, monitoring locations, and impact weights. Environmental monitoring is carried out as an effort to support environmental management. Any infrastructure damage found during monitoring must be corrected immediately. In planning an environmentally safe infrastructure, environmental management and monitoring are needed so that even the slightest damage can be immediately addressed.

The research was carried out in two areas, i.e. Jatinangor and Cilengkrang (Fig. 1). The morphological area is sloping to steep. The lithology found is generally volcanic rock, consisting of volcanic breccia (with weathering), tuff (with weathering), and lava (with weathering). This area is at the foot of Mount Manglayang. The northern part of Mount Manglayang is an adjacent area to the eastern part of the Lembang fault [3]. Characteristics of breccia in Jatinangor consist of clay and silt soil. Some locations are areas with potential expansive soil [4]. These two areas are expected to be developed for various facilities.

![Research Location](image_url)

**Figure 1.** Research location

Based on the study above, some of the problems that will be raised are as follows:

- How is the stability slope of the area?
- How is the soil bearing capacity for foundation of the area?
• If there is expansive soil, how will it be handled?
• What are the directions for environmental management and monitoring?

2. Methods

2.1. Model of Starlet Perdana
Starlet-Perdana stands for Stabilisasi & Rancangbangun Lereng Terpadu – Perkuatan Dayadukung Tanah (Stabilization & Design Integration of Slope – Strengthening of Soil Bearing Capacity). Stabilization and design of slope construction contain a series of activities [5]:

- Engineering geological mapping [6], [7].
- Slope stability analysis [8], [9], [10].
- Simulation of stable slopes design, and slope reinforcement [5], [9], [10].
- Direction of environmental management accompanied by environmental monitoring [11].

Soil bearing capacity covers further studies, namely:

- Analysis of soil bearing capacity
- Analysis of expansive soil
- Direction of environmental management accompanied by environmental monitoring.

2.2. Hexa-helix component
The six of hexa-helix components are Government, Industrial or Business, Community, Education or Academic, Mass Media, Law and Regulation (Fig. 2):

- The government, consisting of the central government and local governments
- Entrepreneurs, industries, business, services and trade
- Community, consisting of society with various professions and non-governmental organizations
- Scientists, including the world of education and higher education
- Mass media and communication media, including means of communication
- Laws and regulations, including local government rules.

The six components have the same view of regional potential and constraints, as well as disasters that damage infrastructure. The same view of disasters is a need to reduce losses and avoid victims. Attention is required, especially to monitor infrastructure damage.
2.3. Slope Stability
To determine slope stability, factor of safety (FS) must be calculated. Factor of safety reflects slope conditions. Based on several landslide events, table 1 from Bowles (1989) gives FS < 1.07 for the usual occurrence of slope failure, 1.07 < FS < 1.25 for slope failure ever occurred, and FS > 1.25 for slope failure events are rare.

| Safety Factor | Slope condition | Meaning          |
|--------------|-----------------|------------------|
| FS < 1.07    | Usually occurrence of slope failure | Unstable         |
| 1.07 < FS < 1.25 | Slope failure ever occurred | Critical         |
| FS > 1.25    | Slope failure events are rare         | Stable           |

Safety factor (FS) is calculated based on slope geometry and physical-mechanics soil properties. The basic formula is shown in Fig. 3 as follows
Stable slope design can be done using a stable slope simulation method. Unstable and critical slopes can be repaired by slope engineering (Figure 4). Factors that influence the level of slope stability are internal and external factors. Internal factors include physical properties of the slope body, slope geometry, depth of Ground Water Level. External factors such as rainfall, climate, erosion, earthquakes or seismic vibrations, and load at the top of the slope.

The general standard for countermeasure of landslide slopes is knowing the causes or triggers. However, not all of these factors can be controlled unless reduced. There are two ways to improve slope stability, namely:

- Reducing the thrust or moment that causes landslides (driving force). The force or moment that causes landslides can be reduce by changing the shape of the slope such as: making the slope and the height of the slope into several terraces (terracing).
- Increases strength or adds moments that cause slope resistance (resisting force). Maintaining strength or moment against landslides can be enlarged by installing gabion (against weight) at the foot of the slope, controlling Ground Water Level (GWL) by making drainage, preventing GWL heights by making drained water passages, and by mechanical means such as mounting retaining walls at the foot of the slope.

2.4. Soil bearing capacity

Soil bearing capacity for shallow foundation is based on the equation of Terzaghi (1948, in [8]. The type or shape of the foundation is divided into three: circular, continuous, and square shape. The Terzaghi equation for calculating the soil bearing capacity of various foundation forms is below this:

- Continues \( q_{ult} = cN_c + qN_q + 0.5 \gamma B N_f \)
- Square \( q_{ult} = 1.3 cN_c + qN_q + 0.4 \gamma B N_f \)
- Circular \( q_{ult} = 1.3 cN_c + qN_q + 0.3 \gamma B N_f \)
The soil bearing value resulting from the Terzaghi equation is smaller than the value obtained from other researchers. Therefore, the Terzaghi equation in [8] is better used, because it reflects anticipation that is greater than the others.

2.5. Soil Improvement
Weathered claystone has typical characteristics in accordance with composition of mineral content. These properties are the nature of swelling, especially if there is water and are easily destroyed if exposed to air or physically damaged in the form of crushed clay, broken into pieces and broken. This last trait is called slacking. The expanding nature can depend on the number of activities (A) of each soil. In general, these properties cause expansive soil, which is easily shrinking and easy to expand according to changes in soil moisture content. If the water content in the soil changes, the volume of
the soil will also change too (Mudjihardjo et al., 1997, in [12]). Clay activity was formulated by a ratio of plasticity index (PI) with percent of clay as presented by Seed et al. (1962, in [13]) namely $A = \frac{(\% \text{PI})}{(\% \text{clay})}$, or the Skempton method, namely $A = \frac{(\% \text{PI})}{(\% \text{clay})}$. $A$ is the activity number, and PI is the Plasticity Index.

3. Result and Discussion

3.1. Safety Factor and Slope Stability Analysis

Safety Factor (FS) is calculated based on slope geometry and physical-mechanical soil properties, such as unit weight ($\gamma$, $\text{T}/\text{M}^3$), cohesion (c, $\text{T}/\text{M}^2$), and angle of internal friction ($\phi$). Slope simulation is done to obtain the relationship between slope angle with FS value. The safety factor calculation results from five samples at Jatinangor are shown in Table 2.

### Table 2. Result of safety factor simulation on various slope conditions at Jatinangor Area [14]

| Slope gradient ($\alpha$, degree) | Safety factor (FS) |
|---------------------------------|-------------------|
|                                 | NGR-2 | NGR-3 | NGR-4 | NGR-6 | NGR-9 |
| 30                              | 0.917 | 1.639 | 1.766 | 1.417 | 1.189 |
| 35                              | 0.86  | 1.564 | 1.681 | 1.349 | 1.119 |
| 40                              | 0.796 | 1.496 | 1.604 | 1.288 | 1.043 |
| 45                              | 0.73  | 1.374 | 1.472 | 1.182 | 0.958 |
| 50                              | 0.691 | 1.322 | 1.416 | 1.137 | 0.911 |
| 55                              | 0.656 | 1.259 | 1.349 | 1.083 | 0.869 |
| 60                              | 0.614 | 1.194 | 1.278 | 1.026 | 0.816 |

Samples NGR-2 and NGR-3 taken from low drainage density area. Samples NGR-4 and NGR-9, taken from high drainage density area. Location of NGR-6 is taken from area around the hilltop at campus Universitas Padjadjaran [14]. The relationship of FS and gradient slope ($\alpha$, at NGR-6) is: $FS = 7.2300 \alpha^{0.474}$. Result of relationship of safety factor (FS) with gradient of slope is give in Table 3.

### Table 3. Meaning of slope stability condition at various degree of slope [14] at NGR-6 and the surrounding area

| Slope (degree) | Safety Factor | Slope condition         | Meaning       |
|----------------|---------------|-------------------------|---------------|
| $\alpha > 56$  | $FS < 1.07$   | Usually occurrence of slope failure | Unstable slope |
| $56 > \alpha > 41$ | 1.07 $<FS < 1.25$ | Slope failure ever occurred | Critical slope |
| $\alpha < 41$  | $FS > 1.25$   | Slope failure events are rare | Stable slope  |

The safety factor calculation results of five samples at Cilengkrang area shown in Table 4. Stability factor is calculated from three simulation region CLK1, CLK2, and CLK3.
Table 4. Result of simulation of safety factor on various slope conditions at Cilengkrang Area

| Simulation Region | Slope gradient (α, degree) | FS, Stability Factor |
|-------------------|-----------------------------|----------------------|
| CLK1              | 30  | 2.280 | 2.054 | 1.917 | 1.783 | 1.671 | 1.554 | 1.447 | 1.347 | 1.248 | 1.149 | 1.049 |
|                   | 35  | 3.396 | 3.071 | 2.916 | 2.741 | 2.597 | 2.449 | 2.284 | 2.144 | 1.980 | 1.818 | 1.662 |
|                   | 40  | 3.227 | 2.956 | 2.851 | 2.751 | 2.628 | 2.534 | 2.480 | 2.432 | 2.382 | 2.337 | 2.283 |
|                   | 45  | 3.091 | 2.794 | 2.655 | 2.498 | 2.423 | 2.232 | 2.084 | 1.956 | 1.807 | 1.659 | 1.517 |
|                   | 50  | 2.941 | 2.691 | 2.597 | 2.508 | 2.397 | 2.310 | 2.264 | 2.219 | 2.174 | 2.134 | 2.085 |
|                   | 55  |      |      |      |      |      |      |      |      |      |      |      |
|                   | 60  |      |      |      |      |      |      |      |      |      |      |      |
|                   | 65  |      |      |      |      |      |      |      |      |      |      |      |
|                   | 70  |      |      |      |      |      |      |      |      |      |      |      |
|                   | 75  |      |      |      |      |      |      |      |      |      |      |      |
|                   | 80  |      |      |      |      |      |      |      |      |      |      |      |

The relationship of FS and gradient slope (α, at CLK1) is: FS = 31.742 α ^(-0.763). Result of relationship of safety factor (FS) with gradient of slope (α) is give in Table 5.

Table 5. Meaning of slope stability condition at various degree of slope at CLK1 and the surrounding area

| Slope (degree) | Safety Factor | Slope condition | Meaning |
|----------------|--------------|-----------------|---------|
| α > 84.5       | FS < 1.07    | Usually failure of slope collapse | Unstable slope |
| 84.5 > α > 69.2| 1.07 <FS <1.25 | Slope failure ever occurred | Critical slope |
| α < 69.2       | FS > 1.25    | Slope failure events are rare | Stable slope |

3.2. Soil bearing capacity

Based on the calculation of soil bearing capacity for shallow foundations in Jatinangor, a continuous foundation form is chosen with the values of allowable soil bearing capacity (qa) as follows in Table 6:

Table 6. Allowable soil bearing capacity at Jatinangor

| Sample | General shear soil conditions, type: Continuous (qa, T/M²) |
|--------|----------------------------------------------------------|
| NGR-2  | 5.895                                                    |
| NGR-3  | 9.552                                                    |
| NGR-4  | 12.785                                                   |
| NGR-6  | 10.156                                                   |
| NGR-9  | 9.420                                                    |

Based on the calculation of soil bearing capacity for shallow foundations in Cilengkrang, a continuous foundation form is chosen with the values of allowable soil bearing capacity (qa) as follows in Table 7:

Table 7. Allowable soil bearing capacity at Cilengkrang

| Sample | General shear soil conditions, type: continuous (qa, T/M²) |
|--------|----------------------------------------------------------|
| CLK4   | 15.744                                                   |
| CLK5   | 39.705                                                   |
| CLK6   | 41.506                                                   |
| CLK11  | 25.324                                                   |
| CLK13  | 27.752                                                   |

3.3. Soil Improvement

The sample tested was a soil sample from Jatinangor. The soil type is silt with high plasticity or MH (based on USCS classification). Plasticity index (IP) = 52.60%, clay percentage is 47.04% [15]. Soil
activity (A) is calculated as $A = 1.12$. According to Bowles (1989), soil is monmorillonitic, which is very active soil.

For comparison, in weathered volcanic (tuff) rocks in Cigintung Village, Malausma District, in Majalengka Regency, with soil type is CH (clay – high plasticity) and MH (silt - high plasticity). The samples tested is showed that the IP plasticity index was between 43.91% and 67.16%. The percentage of clay is between 22% and 50% with a number of A activities between 0.96 to 2.24, or moderate to high soil activity [12], mineral properties from kaolinitic to montmorillonite.

The results of soil activity test by adding CaO to clay from two samples are shown as follows: On soil samples from Jatipangor, the optimum addition of CaO to swelling soil is 15% to 20% CaO [14]. The addition of excessive CaO or more than 20%, tends to change the value of soil activity and increase the level of activity again. This condition is suspected because the chemical properties of weathered volcanic rocks (from breccia and lava) react with CaO [16].

3.4. Direction of Environmental Management and Monitoring

Environmental management & monitoring is required to be taken into consideration for the detailed engineering design and basic implementation of environmental management activities. The aim is to prevent, overcome, minimize or control negative impacts both arising during construction activities and after construction activities.

Environmental management for the foundation begins with the selection of the Safety Factor (usually is 2). Building load may not exceed allowable bearing capacity in accordance with the selected Safety Factor. The addition of CaO must not be excessive. To avoid the activity number (A) that are still high (A > 1) and changes in CaO by acidic rainwater, it is advisable to add at least 15% CaO from the original soil for mixing. In the 15% mixing condition, the activity number drops to <1, if there is an expansive soil, the nature of its swelling can be reduced. In these conditions, the soil bearing capacity increases.

Environmental management for slopes is carried out to deal with the effects of slope instability (especially on road planning) including unstable slope conservation with stable slope simulation methods. The method begins by identifying landslide direction, calculating slope safety factors (FS), making stable slope engineering in an integrated manner so that the quality of the environment after being managed is expected to be better, safer and more stable (Fig. 5), namely:

- Construction of terrace in addition to road construction as well as efforts to improve slopes resistance, especially slopes with large gradient.
- Re-vegetation & construction of retaining walls, especially if there are landslide around the road, on the slopes and in the valley.
Figure 5. Slope reinforcement management model [10]

- Construction of drainage as an effort to control surface water so that water does not enter the body of the slope. The ground water level and water content can be controlled.
- Construction of water drainage by inserting pipes or bamboo into the body of the slope as an effort to reduce the water table. The water coming out of the pipes or bamboo is channeled to the drainage channel at the foot of the slope.

Environmental monitoring is carried out on permanent infrastructure located on the foot of slope and/or above slope locations, especially slopes that are prone to landslides, also on existing road bodies or on retaining walls. Indications of moving slopes can be seen from trees growing irregularly, walls of buildings cracked, houses or buildings tilted to the valley, roads that tilt towards the valley, several cracked road segments, and damaged (cracked) at drainage. Also indications of foundation failure can be seen from buildings tilted, partially cracked, or broken walls of buildings. The slightest damage must be handled immediately.

4. Conclusion
- Slope stability in the study area i.e. Cilengkrang (CLK1) and Jatinangor (NGR-2) shows that the area of Cilengkrang is more stable than Jatinangor. The relationship between FS and angle of slope on the slope with the smallest FS in Cilengkrang is: $FS = 31.742 \alpha^{-0.763}$. The slope is stable when angle of slope is less than 69.2°. The relationship between FS and angle of slope on the slope with the smallest FS in Jatinangor is $FS = 7.2300 \alpha^{-0.474}$. The slope is stable when angle of slope is less than 41°.
- The type of foundation chosen is a continuous form. In Jatinangor, allowable bearing capacity ($qa$) for continuous type is 5.89 T/M² to 12.79 T/M². In Cilengkrang, allowable bearing capacity ($qa$) for continuous type is 15.74 T/M² to 41.51 T/M².
- For potential expansive soil, the soil can be improved by adding CaO 15%. At the 15% mixing condition, the activity number (A) drops to <1. In this condition, characteristic of expansive soil can be reduced, and soil bearing capacity will be increase.
- Infrastructures can be managed and monitored. In environmental management and monitoring, hexahelical components can play a role so that the built infrastructure will be safe and durable. Engineering slopes will be strong for a long time without failure. The foundation can be safe without failure.
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