SLOPE STABILITY ANALYSIS OF EAST RING ROAD CONSTRUCTION AT SADAWARNA DAM WITH SHEAR STRENGTH REDUCTION METHOD

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ABSTRACT

Slope stability has been a problem that studied on geotechnical works for the uncertainties such as varieties of soil behaviours to unpredicted failure of measurements and samplings. The Limit Equilibrium Method (LEM) has been popular for decades for its convenience but cannot determine displacement thus the result could be uncertain. As computational calculations have been developed, the Finite Element Method (FEM) began to use as a tool to not only determine factor of safety, but also determine displacement and forces that affect slope's stability. This research was done to analysed slope stability using Shear Strength Reduction (SSR) and compared it to general method such as Limit Equilibrium Method (LEM). The research was conducted on a section in Sadawarna DAM ring road area, Subang, West Java. Slope on research area was divided into two layers with the bottom layer relatively non-cohesive compared to the top of layer. Both soil however dominantly consist with fine grain soil such as silt and clay. The upper layer of slope can contain more water with liquid limit of 73,46% compared to the lower layer with 68,27% liquid limit. Simulation result showed slope that analysed using SSR method has Factor of Safety (FoS) 0,12 lower than LEM method. SSR method could be used to analysed pessimistic value at worst scenario and could predicted deformation of slope.

Keyword: Limit Equilibrium, Strength Reduction Factor, Finite Element Method, Soil Mechanic, Displacement

INTRODUCTION

Slope stability is an issue that commonly studied at geotechnical engineering. Slope stability studies are conducted to obtain factor of safety, which commonly associated with infrastructure development (Zakaria and Jihadi, 2017). Slope stability becomes an interesting study where analyses to determine stability of the slope often encounter uncertainties (Zhao *et al*., 2020). Uncertainties in slope can be cause by several factors, including variations in soil properties, changes in environmental conditions, geological anomalies, and unexpected measurement and sampling failures (El-Ramly *et al*., 2002).

Over the decades, slope stability has posed a challenge for experts to accurately assess field conditions. Therefore, slope stability analysis methods continue to evolve, with earlier analyses involving slopes with soil materials (Zakaria *et al*., 2018). One of the first methods is the Limit Equilibrium Method (LEM), which is used to analyse dam failures. Since then, this method has undergone developments such as the use of vertical slices in slope analysis (Fellenius, 2023) and force equilibrium between slices (Bishop, 1955). Another development is the determination of safety factor with the assumption of non-circular slipe surface (Morgenstern and Price, 1965).

The LEM principle on slopes can be explained as the ratio of soil shear strength to slope shear stress required to achieve equilibrium (Duncan, 1996)(Dawson *et al*., 1999). This principle is considered simple enough to describe slope stability and remains popular until now. However, there is a limitation which the assumption of the slip surface is not always accurate as well as the shear strength of the material along the slip surface is assumed to be uniform. (Duncan and Wright, 1980).

As computational calculations have advanced, other methods have been developed, such as the Finite Element Method (FEM) (Veubeke, 1964). This method can determine equilibrium on slopes without applying conformity of the formula (Veubeke, 1964). This method then became known as a good method in slope stability analysis because it can estimate deformations and displacements on the slope (Veubeke, 1964)(Salunkhe *et al*., 2017). With the advancement of technology, slope stability can be simulated with this principle, and this method has been developed to reduce shear strength on the slope until it reaches failure (Dawson et al., 1999; Matsui and San, 1992).

Sadawarna Dam is one of the recent dams in Indonesia than serves as a water source for three districts in West Java. It serves as reservoir for water that mostly arrived from Cipunagara River. Despite being operated,

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Sadawarna Dam is still undergoing construction, including construction of road relocation and other essential infrastructure (Sitepu and Pontan, 2021). Road construction on steep slopes then has the potential for landslides to occur (Allison *et al*., 2004). FEM can be used as a method to estimate slope failure and its deformations using the Shear Strength Reduction (SSR) approach.

RESEARCH METHOD

The research area is located on the slope of the East Ring Road development at the Sadawarna Dam, West Java. The research involves a section of the natural slope. The slope consists of two layers with a high degree of weathering (from the Completely Weathered Zone to the Top Soil).

Figure 1. Slope’s Observation Point

The soil mechanical properties are obtained from direct shear test, while the soil unit weight values are obtained from soil physical property tests. Slope stability simulation is conducted by using the shear strength properties of soil, such as cohesion and angle of internal friction, as well as the unit weight, into the calculations. The slope is simulated under four different conditions, representing increasing moisture content in each condition: dry, optimum, natural, and saturated. The determination of the optimum moisture content for each layer is done through a light compaction test on disturbed soil that passes through a No.4 sieve.

Shear Strength Reduction

Shear Strength Reduction (SSR) is a method to reduce the shear strength of slope until failure (Matsui and San, 1992) (Dawson et al., 1999). This method becomes popular when computer became more advanced. (Cala M. & Flisiak J., 2003).

The slope factor of safety is based on the safety factor values resulting from a slope that fails as the shear strength of the slope is continuously reduced (Dawson et al., 1999). This method uses Strength Reduction Factor (SRF) as parameter to show slope’s stability (Sihotang et al., 2019). By applying the

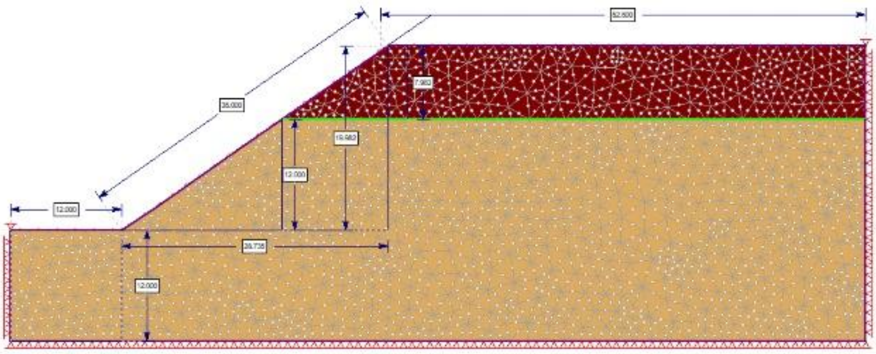

Figure 2.Slope’s Geometry

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principle of shear strength reduction on the slope, the mechanical properties of soil that use the Mohr-Coulomb failure criteria can have their reduction values determined using the following equation.

$$C' = \frac{C}{F},\ \phi' = arc\tan(\frac{\tan\phi}{F}) ....(1)$$

Where C and C′ are initial cohesion and cohesion when failure occurs. φ and φ′ are initial internal angle of friction and angle of friction when failure occurs. With this equation, the minimum shear strength of soil before failure can be determined.

RESULT AND DISCUSSION

Based on the physical and mechanical property tests on two samples representing each layer of the slope, it was found that UDS 8.1, which represents the lower layer of the slope, has a clay percentage of 60.78%, silt of 26.92%, and sand of 12.3%. The relatively high sand percentage makes this soil considered as non-cohesive soil. In the upper layer of the slope (UDS 8.2), the percentage of clay is 51.72%, silt is 47.12%, and sand is 1.16%. The lower sand content in comparison to UDS 8.1 suggests that this soil has a higher cohesion value compared to UDS 8.1.

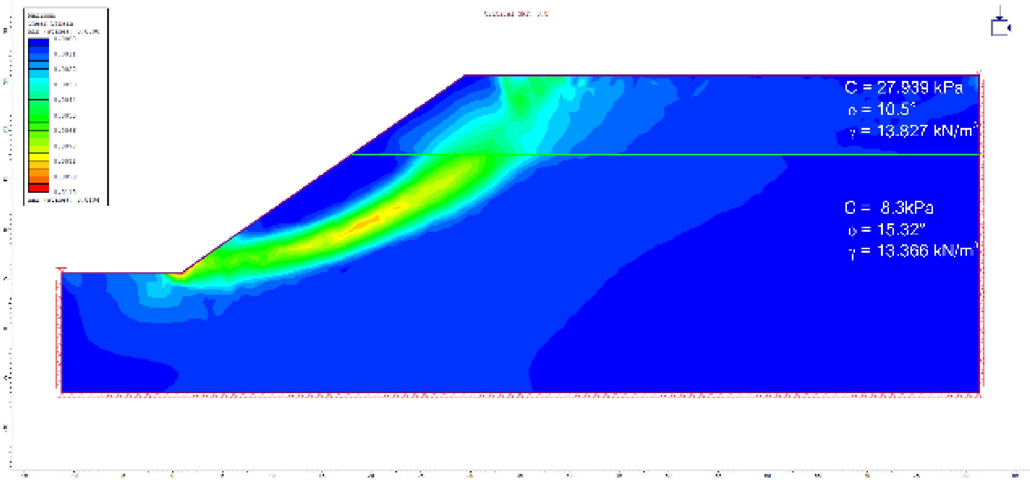

Figure 3.Simulation Result Using Shear Strength Reduction

Table 1. Sieve Analysis Result of Slope Materials

No	Sample	Weathering	Sieve Percentage			
			Gravel (%)	Sand (%)	Silt (%)	Clay (%)
1	UDS 8.1	CWZ	0	12,3	26,92	60,78
2	UDS 8.2	Top Soil	0	1,16	47,12	51,72

The soil consistency based on the liquid limit, plastic limit, and plasticity index, it was determined that the soil type of both layers is high plasticity silt (MH), as obtained from the Cassagrande curve. Layer UDS 8.2 has a greater soil consistency compared to UDS 8.1, which means it can retain more moisture content before reaching the saturation phase.

Table 2. Soil Consistency of Slope's Materials

No	Sample	Weathering	Soil Consistency

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			(LL) (%)	(PL) (%)	(PI) (%)	(USCS)
1	UDS 8.1	CWZ	68,27	24,26	44,01	MH
2	UDS 8.2	Top Soil	73,46	47,76	25,7	MH

The unit weight and shear strength of soil are used as parameters on slope stability. The test results show that unit weight and cohesion values of slope's top layer (UDS 8.2) has higher value than slope's below layer (UDS 8.1), meanwhile internal angle of friction of UDS 8.1 has higher value than UDS 8.2.

The slope stability analysis was then conducted using Shear Strength Reduction Method. The result shows that the critical Strength Reduction Factor (SRF) has a value of 0,8, which indicates failure of slope when shear strength parameters reduced 0,8 times from the initial shear strength value.

Another analysis was conducted on the same slope using same shear strength values using Limit Equilibrium Method (LEM) with the Bishop method. The result was a more optimistic with the values of 0,92 compared to the SSR method, indication a higher factor of safety.

Table 3. Unit Weight and Shear Strength Values of Slope's Materials

Layer	Unit Weight (kN/m3)	Cohesion (kPa)	Internal Angle (°)
UDS 8.1	13,366	8,300	15,32
UDS 8.2	13,827	27,939	10,50

CONCLUSION

Based on the analysis, several conclusions can be drawn as follows:

1. The grain size of the slope materials is dominated by clay. The lower layer of the slope contains a larger proportion of non-cohesive particles compared to the other materials.
2. This non-cohesive behaviour is further reflected in the shear strength values, where UDS 8.1 material exhibits lower cohesion but a larger internal friction angle, which is reflects non-cohesive soil behaviour.
3. Based on the slope stability simulations, it was observed that the safety factor values obtained using Shear Strength Reduction (SSR) method are more pessimistic that those obtained using Limit Equilibrium Method (LEM). This difference arises from the fact that in the SSR method, the slope body is subdivided into small grids, resulting in different soil displacements until failure occurs. As a result, the SSR method provides a more accurate and pessimistic safety factor compared to LEM, which only calculates shear strength within the potential failure surface.
4. The SSR method predicts deformations on the slope with a maximum material displacement of

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0,110 meters when the slope is stable and 1,9 meters when the slope fails.

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APPENDIX

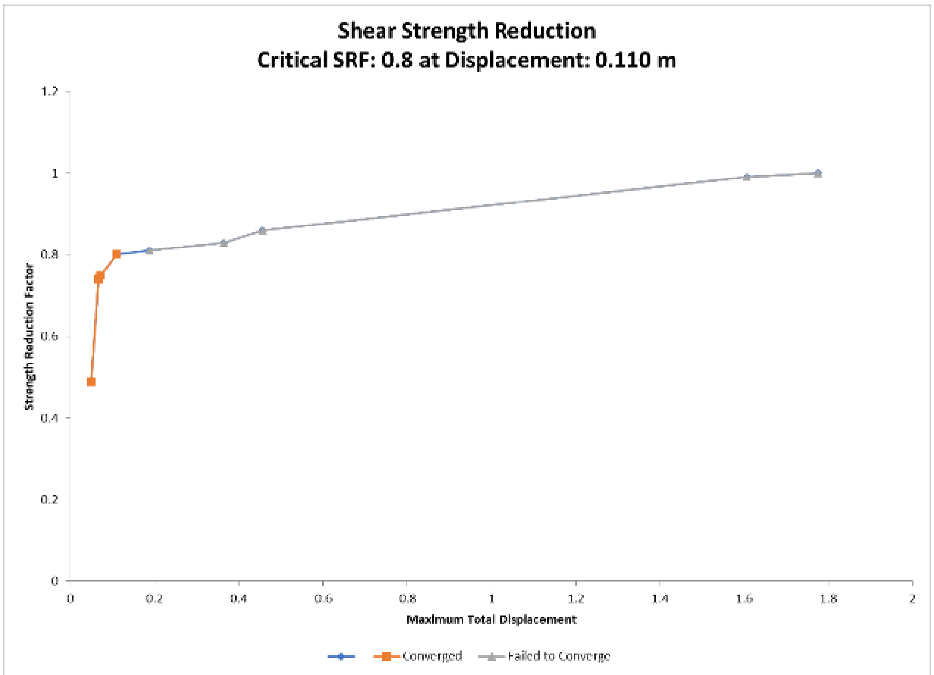

Figure 4. SRF vs Maximum Total Displacement at SRF 0,8

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