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# Stability Analysis of Nickel Haul Road Embankment Slopes in Southeast Sulawesi

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**ABSTRACT** The stability of embankment slopes is strongly influenced by the embankment material. Embankments are often constructed for mining haul roads, and those roads are subjected to large loads with high intensities. In this paper, stability analysis of a nickel haul road in Southeast Sulawesi is presented. For the case presented in this paper, the embankment is constructed on a saprolite layer using lateritic soil. Boreholes were conducted along the haul road to determine the soil profile. Disturbed samples of the lateritic soil were also taken to obtain its compaction behaviour and shear strength. Based on the soil stratigraphy and fill material properties, a parametric study varying the slope height (2.5 m to 10 m) and slope inclination (25º to 45º) is conducted. The results show that safety factors vary approximately linear with slope inclination, while safety factors reduce with increasing slope height, but at a reducing rate. Overall, even at the highest slope height and steepest slope inclination, a factor of safety higher than 1.3 is still obtained. That means the haul road embankment can be built safely for the site analyzed in this paper.

**KEYWORDS** Laterite soil; embankment; slope stability; haul road

## 1 INTRODUCTION

In slope stability analysis, many factors are considered starting from site investigation, soil selection, to soil mechanical properties (Adeoti et al., 2023). In civil engineering and mining industries, slope stability is one of the important aspects that must be considered to support their respective activities, one of which is embankment slope intended for roads. Especially in mining, haul road stability is of utmost importance as failure can hinder mining operation. In addition, haul road tends to be filled to great height, making the embankment prone to failure, especially if the slopes are derived from borrowed earth of poor quality and poorly compacted (Aqib et al., 2023). Existing research (Liu and Hounsa, 2018) states that factors that affect embankment slope stability are self-weight and shear strength of the embankment, slope geometry, and also the traffic load on the road embankment.

PT Sulawesi Cahaya Mineral (PT SCM), a company located in Southeast Sulawesi, is engaged in the nickel laterite mining business. Like most mining operation, PT SCM also requires haul road. This paper shares the stability analysis conducted for nickel haul road of PT SCM. Nickel is a very important industrial metal and is widely used in various fields such as steel, metal alloys, electroplating, batteries, and magnetic materials (Zhang et al., 2025). Nickel laterite is formed through natural weathering processes in mafic and ultramafic rocks in tropical to sub-tropical climates. In Southeast Asia, known for its tropical rainforest climate, nickel deposits of this type are widely developed and have become one of the important natural resources for industry (Qi et al., 2024).

Lateritic material, material abundant in Southeast Sulawesi, is a soil material formed weathering of parent rock which is rich in $SiO_2$ and $Fe_2O_3$, resulting in its reddish color and high water absorption

(Irwan and Nursiadi, 2024; Irwan et al., 2024). Slope stability planning in laterite zone face challenges where the laterite soil profile is strongly influenced by rainfall and tends to erode easily in high rainfall conditions (Shivashankar et al., 2019). The lithological profile found in PT SCM includes laterite nickel deposits that occur from the weathering of complex ophiolite rocks, such as peridotite, serpentinite, dunite and gabbro. The nickel laterite lithology at PT SCM mine has 4 zones based on the results of subsurface exploration (Figure 1), namely the soil/ferrogenous zone layer, limonite, ferrogenous saprolite and soft saprolite transition zone, rocky saprolite and bedrock. These lateritic materials are often used as material for embankment.

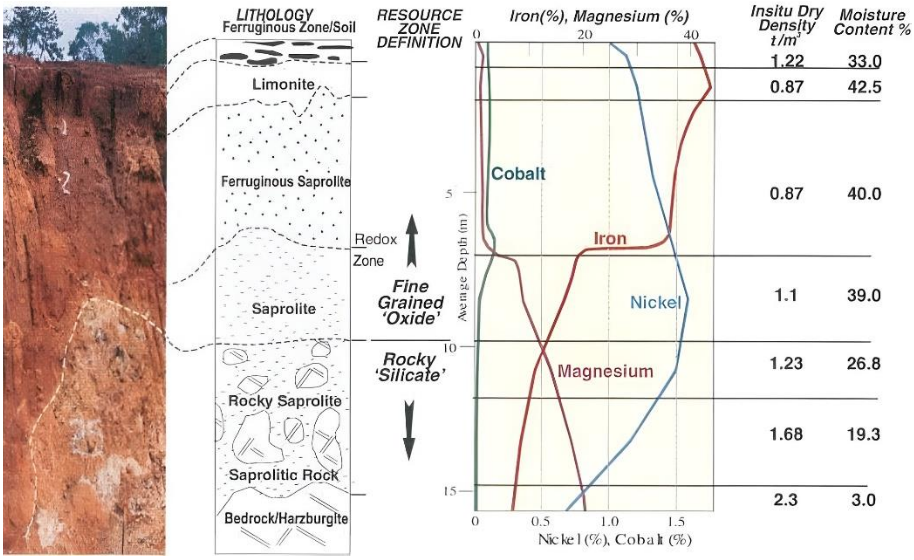


Figure 1. Laterite profile and geochemistry of nickel deposits

Depending on the weather, clay-dominated soils can have difficult workability, resulting in sub-optimal compaction. When the optimal compaction is not achieved, the working load on the embankment can result in excessive deformation (Boru et al., 2022). Especially embankment slopes used for mining haul roads, in which the traffic load is higher, and can be intensive during operational hours. Research by (Chao et al., 2024) states that the repetition of loads by vehicles will cause cyclic stress on road embankments and can result in progressive shear failure. In this paper, the research is aimed at analyzing the characteristics and suitability of laterite soil when used as a mining road embankment material in Southeast Sulawesi stratigraphy.

## 2 SOIL PROPERTIES AND NUMERICAL MODELLING

Figure 2 shows the haul road plan and location where drilling samples along the haul road are taken. A total of 17 boreholes were conducted. GT-13 (marked in red square in the figure) are chosen for this study. At GT-13, the top 5 m consists of heavily weathered saprolite, underlain by bedrock layer.

To characterize the laterite soil characteristics, disturbed samples were taken, and laboratory tests were conducted to evaluate its properties. The laboratory tests conducted included sieve analysis and hydrometer, specific gravity test, Atterberg limits test as well as standard proctor tests. The samples compacted at 95% dry of optimum were tested for their shear strength using direct shear test, as well as indirectly using CBR. The laboratory test results are shown in Table 1.

Figure 3 shows the geometry of the haul road for section in proximity of GT-13 is 5 m embankment with a slope angle of 30º. To give a feel of the suitability of the laterite for other haul road sections, parametric numerical study using embankment height of 2.5 m to 10 m at 2.5 m interval, as well as slope angle ranging from 25º to 45º at 5º interval was conducted. A total of 20 numerical runs were conducted. Table 2 shows the parameters used for the analysis. The constitutive model used is Mohr-Coulomb in drained conditions. For the embankment, the lowest shear strength was taken, whilst for the saprolite, the shear strength was taken from Hamza et al. (2019) and Rigo (2005). As for bedrock, the shear strength is taken from Agliardi et al. (2013). It is assumed that there is no ground water table.

The numerical analysis was conducted using Plaxis 2D. After the initial generation of stress, the embankment is constructed, followed by application of traffic load. The traffic load applied follows the specifications of the Hino 500 Truck 11.00-20-wheel type, giving a 40 kPa traffic load. A 2 m distance from the edge of the slope was given before application of traffic load (Figure 3).

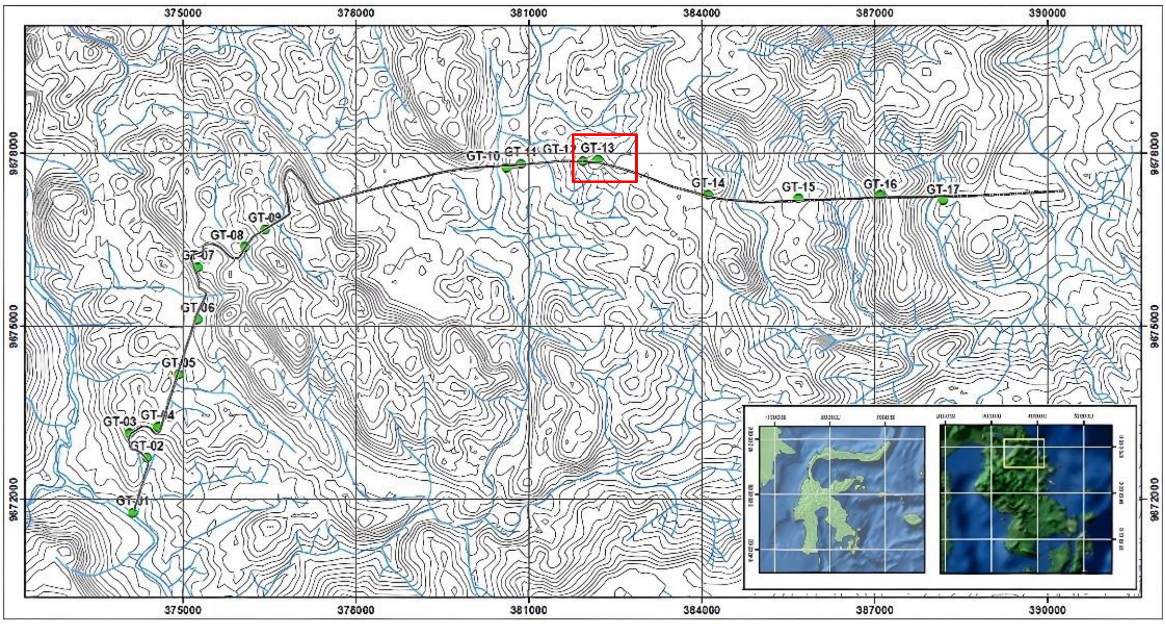


Figure 2. Borelog locations and the one chosen for the numerical modelling

Table 1. Laboratory results of the laterite samples

| Sample | | Unit | 1 | 2 | 3 |
|---|---|---|---|---|---|
| Specific Gravity | | - | 2.637 | 2.656 | 2.621 |
| Atterberg Limit | Liquid Limit (LL) | % | 61.48 | 41.93 | 45.66 |
| | Plastic Limit (LL) | % | 48.59 | 32.60 | 36.35 |
| | Plasticity Index (PI) | % | 12.89 | 9.32 | 9.32 |
| | Shrinkage Limit (SL) | % | 11.89 | 14.52 | 8.31 |
| Grain Size | Gravel | % | 1.20 | 2.20 | 1.60 |
| | Sand | % | 6.80 | 7.80 | 5.80 |
| | Silt | % | 47.43 | 46.59 | 47.57 |
| | Clay | % | 44.57 | 43.41 | 45.05 |
| USCS | Soil Classification | - | MH | ML | ML |
| Proctor test | Optimum Moisture Content | % | 31.9 | 28.5 | 28.6 |
| | Maximum Dry Density | kN/m$^3$ | 14.16 | 14.24 | 14.22 |
| Direct shear test | Friction angle | $^o$ | 24 | 26 | 26 |
| | Cohesion | kPa | 80 | 88 | 84 |
| CBR | | % | 12.96 | 12.24 | 15.66 |

Table 2. Input parameters for numerical modelling

| Parameters | Unit | Embankment | Saprolite | Bedrock |
|---|---|---|---|---|
| Unsaturated Density ($\gamma_{unsat}$) | kN/m$^3$ | 16.8 | 17.0 | 27 |
| Cohesion (c) | kPa | 80 | 52.3 | 200 |
| Friction Angle ($\phi$) | degree | 24 | 34.9 | 32 |
| Modulus Young (E) | kPa | 12000 | 40000 | 5.5E6 |
| Poisson Ratio ($\upsilon$) | - | 0.3 | 0.38 | 0.2 |
| Compressibility Index ($C_c$) | - | 0.182 | - | - |

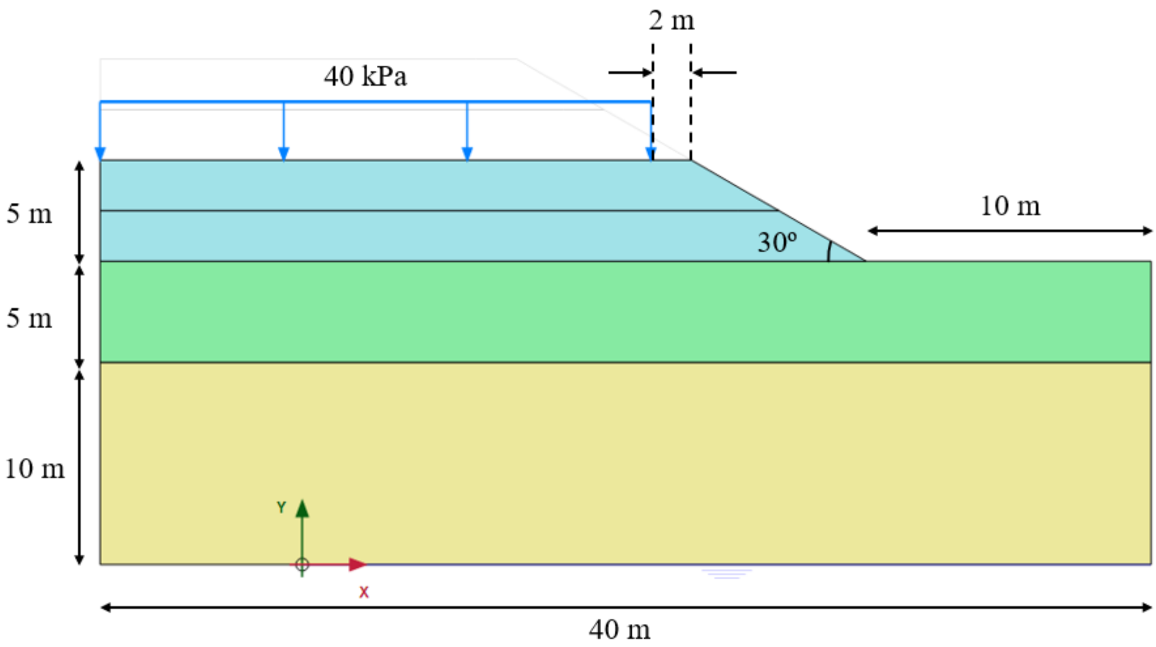


Figure 3. Haul road slope geometry

## 3 RESULTS

### 3.1 Section GT-13

For the section that is to be built on section GT-13, i.e., slope height of 5 m with slope angle of 30º, a settlement of 3.5 m is obtained (Figure 4). The safety factor obtained with this configuration is 5.02, with failure envelope shown in Figure 5. The safety factor is much higher than the minimum required of 1.3. The high safety factor is attributed to the high strength of saprolite, as well as the embankment fill material.

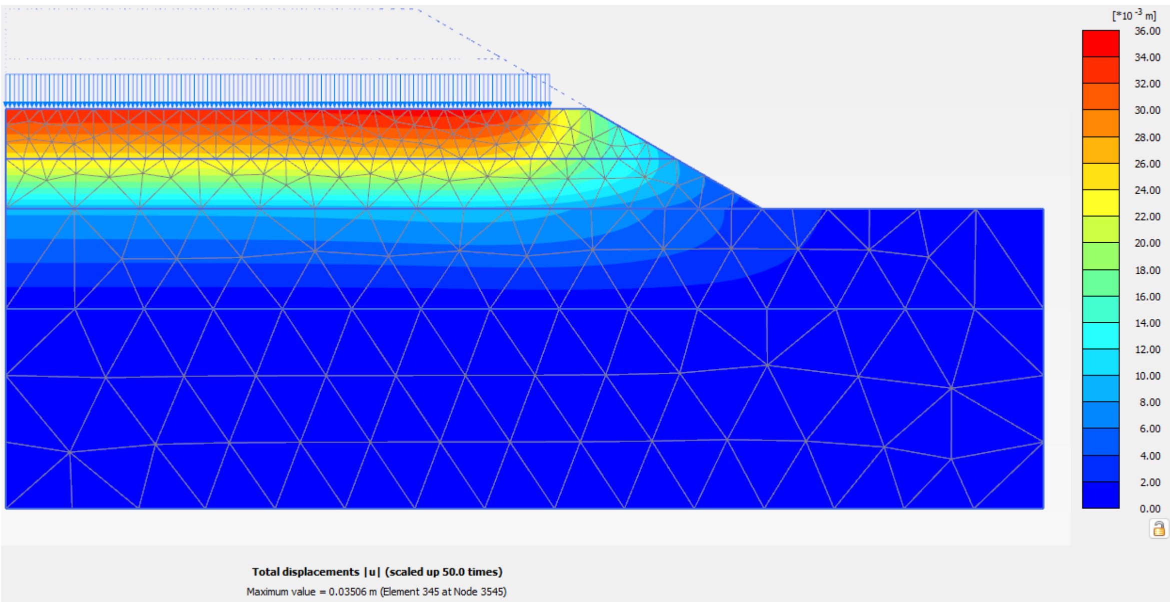


Figure 4. Deformation during traffic operation, maximum deformation = 3.5 cm

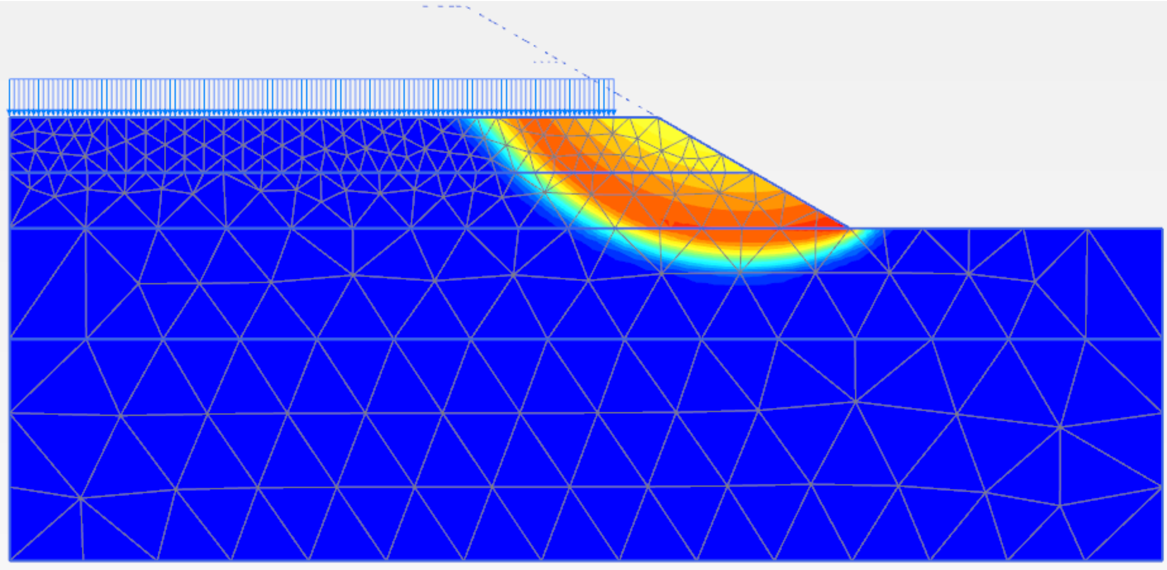

Figure 5. Failure envelope for 5 m high slope with slope angle of 30º

### 3.2 Effects of varying slope height and inclination

Table 4 shows the safety factor obtained for varying slope height and inclination. To better visualize the effects of slope height and slope inclination on the safety factors, two graphs with different x-axis are plotted. The first graph, figure 6, shows the evolution of safety factors against slope angles for various slope heights. As for the second graph, figure 7, shows the evolution of safety factors against slope height for various slope angles. As expected, the lowest fill height with gentlest slope inclination obtain the highest safety factor of 6.85. On the opposite end, the highest fill height with steepest slope inclination obtains the lowest safety factor of 3.01. Despite the high height and relatively steep inclination, the laterite fill on saprolite still obtain very high safety factor, much higher than the required 1.3.

Taking a look at figure 6, the influence of slope inclination on safety factors are relatively linear for all slope heights, with a reduction of 0.3 for every 5 degrees of inclination. This is probably because the increase in disturbance force is a sine function of the slope inclination and the sine values between 25º to 45º are approximately linear. From figure 7, the trend is no longer linear. Increasing slope height reduces the safety factor, but at a reducing rate. The highest drop in safety factor occurs when the slope height is increased from 2.5 m to 5.0 m, a drop of 1.5 to 1.7 for slope angle 25º to 45º. Subsequent increase in slope height shows a lesser drop in safety factor, 0.8 for slope height increasing from 5.0 m to 7.5 m, and 0.5 for slope height increasing from 7.5 m to 10 m. This is because slope height is a direct function of disturbing force. An increase from 2.5 m to 5.0 m essentially doubles the disturbing force, but an increase from 5.0 m to 7.5 m is a 50% increase. Likewise, an increase from 7.5 m to 10 m is an even lower increase of 33%. Hence the reduction in safety factors decreases with increasing slope height.

Table 3. Safety factors for various slope height and inclination

| Parameter | | Fill Height (m) | | | |
|---|---|---|---|---|---|
| | | 2.5 | 5.0 | 7.5 | 10.0 |
| Slope Angle (°) | 25 | 6.85 | 5.39 | 4.59 | 4.08 |
| | 30 | 6.57 | 5.02 | 4.20 | 3.70 |
| | 35 | 6.32 | 4.73 | 3.90 | 3.40 |
| | 40 | 6.15 | 4.48 | 3.68 | 3.17 |
| | 45 | 5.97 | 4.30 | 3.51 | 3.01 |

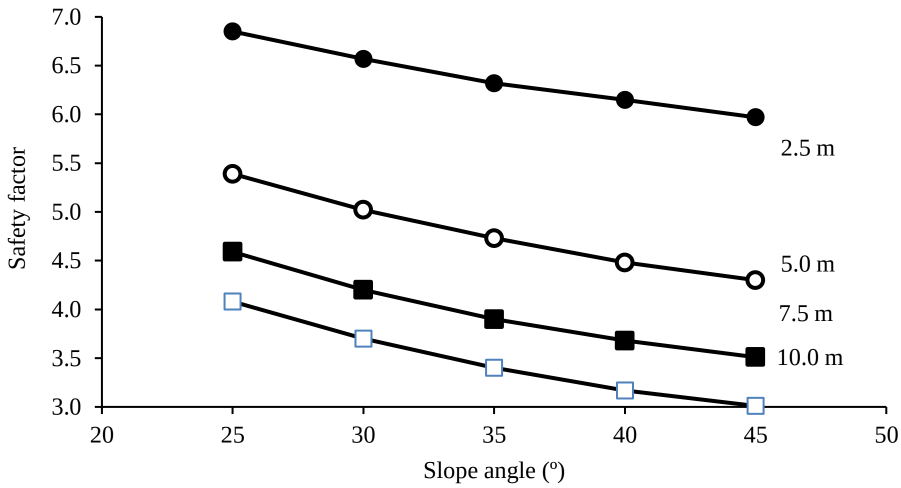


Figure 6. Safety factors against slope angle for various slope heights

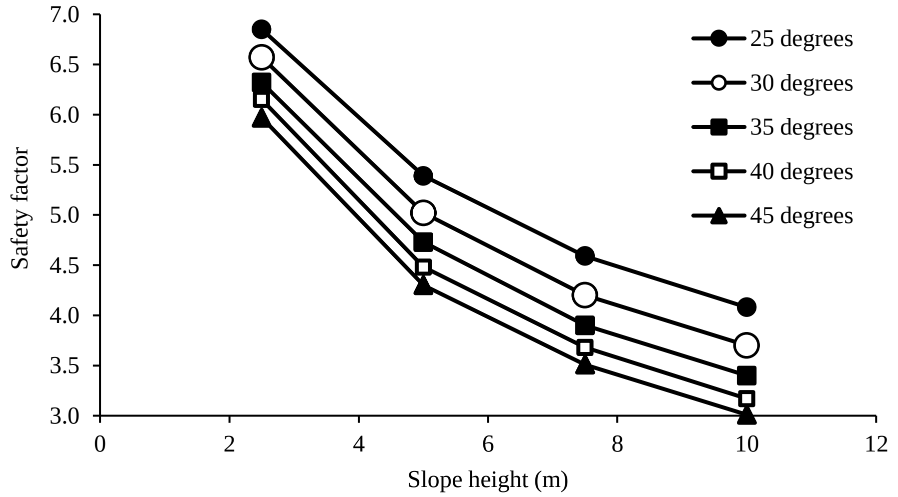


Figure 7. Safety factors against slope height for various slope angles

## 4 CONCLUSION

From the laboratory tests of disturbed samples, the shear strength obtained of laterite is quite high, especially if compacted to 95% dry of optimum. In addition to the high laterite strength, the saprolite layer in which the embankment is to be built upon also has high shear strength. This is shown from the high safety factor obtained (5.02), which is much higher than the safety factor obtained. From the parametric study conducted, for the given laterite properties and saprolite layer, up to 10 m high embankment with 45º can be built safely. The parametric study also shows that safety factor decreases almost linearly with increasing slope inclination. Another finding is that safety factor decreases with increasing slope height, but at a reducing rate. Although this study shows that embankment can be built safely on Southeast Sulawesi soil, the authors would like to remind readers that the soil properties showcase in this study may not be reflected in other parts of Southeast Sulawesi. Soil investigation still has to be conducted to determine the subgrade properties, and disturbed samples still have to be taken to determine the compaction properties and shear strength of fill material. Quality control of the compaction is also another important factor to ensure slope stability.

**DISCLAIMER**

The authors declare no conflict of interest.

**AVAILABILITY OF DATA AND MATERIALS**

All data are available from the author.

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