Analysis slope stability of transmission tower 150 kV on moderately-cemented-sand due to soil excavation

R Rasgianti* and P A Wibowo
PT PLN (Persero), Research Insitute, Duren Tiga Raya Street 102, Jakarta. 12760, Indonesia

*rasgianti@pln.co.id

Abstract. T.66, transmission tower of 150 kV line Cilegon Baru – Asahimas was in high light for the threaten of slope stability because of soil mine excavation around tower area. Massive Excavation soil were occurring next to tower foundation, which is the depth approximately 14 m (height) and the inclination almost 80°. Therefore, analysis was highly needed to ensure that tower stand on stable spot. The method used in this research were study literature, soil investigation (deep boring and hand boring) and laboratory test for undisturbed samples, geoelectric test, and topography mapping. The type of soil was ‘moderately cemented sand’ slope. It has a complete characteristics and tends more challenging in determine the slope stability. By considering that, the data parameters input were approached in conservative way, which was considering literature and soil investigation data. In this case, slope stability was modeled with Finite Element Method (FEM) by doing back analysis. The result shown that tensile stress was relative small (near 0).

1. Introduction
Massive excavation occurred in an extremely big area around the spot of the tower. The problem is, this activity only left for the spot of ROW (Right of Way) of the tower with inclination was almost 80° and its elevation is circa 14 m from the ground. It potentially has a risk for the stability of the tower. Those conditions can be seen in Figure 1. Visually, the soil was dominated by sandstone/cemented sand [1]. The inclination explained that the cementation in material performs a cohesive and could fail in brittle fashion [2] and also has high strength bond of the materials [3,4].

Figure 1. The condition of tower area after excavation (PLN Documentation).
2. Methods
Slope stability of sandstone analysis divides into two methods based on the cementation level; weakly cemented sand slope and moderately cemented sand slope [5]. Weakly cemented sand slope can be analyzed with limit equilibrium, and moderately cemented sand slope analyzes by comparing tensile strength that occur on the slope to the materials tensile strength in an undisturbed condition. Soil investigation (hand bored, deep bored, and geoelectric) was carried out to determine the type of sandstone. Undisturbed sampling is hard to done for cemented soil [6], otherwise hand bored was held to approach soil properties. Furthermore, properties sandstone was set based on the literature, soil laboratory test, and reverse engineering analysis.

3. Results and discussion

3.1. Geological study
The location of tower is in formation the old volcanic sediment in formed upper Banten tuff (Qvtb) which is composed of various kinds of tuffs, so with clayey intercalations.

3.2. Topography mapping

Figure 2. Topography mapping.

Figure 2 was a layout of tower which shown the contour and position of soil investigation work. There were 2 points hand-bored (HB 1 and HB 2), 1 point deep-bored (DB 1), and 2 line geoelectric tests (line A and line B).
3.3. Hand bored and deep bored

Hand bored was held at the elevation of the tower. Undisturbed sample was taken at 1 m below the surface. The laboratory test shown that the surface soil still contains of clay. The visual observation can be seen from the cutting side of the edge excavation. The soil is covered by surface layer. It cannot represent the soil beneath in the under surface.

Deep bored was held on the ground of excavation, because it was too risky to execute at the tower elevation. Undisturbed sample was obtained at the depth 2 m. It could not get the sample at deeper because material of soil is high density sand. It was proved by the grain size distribution test that the sample was dominated by sand approximately 49% – 53%. The evaluation of possibility liquefaction [7] from that percentage is very large as shown in Figure 3.

![Figure 3. Possibility of liquefaction evaluation (OCDI Japan 2009).](image)

Furthermore, it also needs to be checked based on the value of equivalent N-value and equivalent acceleration [2]. Figure 4 shown the condition with high density sand material which has an average value of N-SPT >60 (blows/30 cm), equivalent N-value is obtained > 25. Therefore, this location has a very low possibility of liquefaction or it will not occur. As cemented sand can reduce the potential of liquefaction [8].

![Figure 4. Liquefaction evaluation based on equivalent N-Value (OCDI Japan 2009).](image)
3.4. Geoelectric Survey

The geoelectric test used an ARES with 6 cable dipole-dipole electrode configuration. It is a kind of geophysical test to determine the subsurface layer of soil based on electrical resistivity. As the reference, the table 1 is used to interpret the data [9] from the survey.

| Materials                                      | Resistivity |
|------------------------------------------------|-------------|
| Clayey soils: wet to moist                      | 5-10        |
| Silty clay and silty soils: wet to moist        | 10-50       |
| Silty and sandy soils: moist to dry             | 50-500      |
| Bedrock: well fractured to slightly fractured with moist soil-filled cracks | 500-1000 |
| Sand and gravel with silt                       | About 1000  |
| Sand and gravel with silt layers                | About 300   |
| Bedrock: slightly fractured with dry soil-filled cracks | 100-800 |
| Sand and gravel deposits: coarse and dry        | >8000       |
| Bedrock: massive and hard                       | >8000       |
| Freshwater                                      | 67-200      |
| Seawater                                        | 0.6-0.8     |

*From SoiIest, Inc.*

Note: (1) In soils, resistivity is controlled more by water content than by soil minerals. (2) The resistivity of the pore or cleft water is related to the number and type of dissolved ions and the water temperature.

**Figure 5.** Line A geoelectrical test (at elevation of tower).

**Figure 6.** Line B geoelectrical test (at elevation of excavation Ground).
3.5. Soil stability analysis
Considering all those aspects above, parameters for analysis was also determined by the reverse analysis method is shown in table 2. Those tend to conservative but representative.

| Material    | $\gamma$ (kN/m$^3$) | c (kN/m$^2$) | $\phi$ (°) | E (kN/m$^2$) | v    |
|-------------|----------------------|--------------|------------|-------------|------|
| Sandstone   | 17                   | 50           | 40         | 50000       | 0.3  |

Table 2. Assumption of parameters for finite element analysis.

Figure 7. (a) Plane strain 2D model; (b) Mechanism of slope failure.

A critical section was chosen to be modelled into 2D plain strain with Plaxis v.6 software, see Figure 7(a). The soil was assumed as a homogeneous. And Figure 7(b) shown the value of the safety factor with numerical simulation that was obtained 2.38. And the positioning mechanism of slope failure is 10 m from the edge of the cutting side. It can be interpreted that slope was stable.

Figure 8. Tensile distribution.

Besides, as seen in figure 8, finite element method analysis shown that the distribution of tension strength is 0.

4. Conclusion
Basically, material of moderately cemented sand tends to having a good physical behavior, but it has to be conditioned under undisturbed. External factors that could be a threat are; (a) Erosion at the surface, especially at slope next to the ground; (b) Saturated condition can decrease the tension stress of soil [10]. Therefore, all the surface has to be covered with shotcrete and wire mesh.
Acknowledgment
We would like to thank many peoples who have helped us for this entire project. This work was funded by the PT. PLN (Persero) Research Institute.

References
[1] Blyth F G H and de-Freitas M H 2005 A Geology for Engineers, 7th Edition Elsevier Butterworth-Heinemann.
[2] Collins B D and Sitar N 2009 Geotechnical Properties of Cemented Sands in Steep Slopes Journal of Geotechnical and Geoenvironmental Engineering 135 10.
[3] Obermyr M, Dressler K and Eberhard P 2013 A Bonded-Particle Model for Cemented Sand Computers and Geotechnics 49 Elsevier
[4] Rakimzhanova A K, Thornton C, Minh N H, Cheong F S and Zhao Y 2019 Numerical Simulation of Triaxial Compression Tests of Cemented Stanstone Computer and Geotechnics 113 Elsevier.
[5] Collins B D and Sitar N 2011 Stability of Steep Slopes in Cemented Sands Journal of Geotechnical and Geoenvironmental Engineering 137 1
[6] Haeri S M, Shahcheraghi S A, Shakeri R and Seiphoori A 2009 Mechanical Behavior of a Cemented Haraveli Sand under Monotonic and Cyclic Loading-Case Study of Tehran Alluvium 8th International Congress on Civil Engineering Shiraz University, Iran
[7] The Overseas Coastal Area Development Institute of Japan (OCIDI Japan) 2009 Technical Standards and Commentaries for Port and Harbour Facilities in Japan.
[8] Surendra K, Saxena S K, Reddy K R and Avramidis A S 1988 Liquefaction Resistance of Artificially Cemented Sand Journal of Geotechnical Engineering 114 12
[9] Hunt R E 2005 Geotechnical Investigation Methods: A Field Guide for Geotechnical Engineers Taylor & Francis Group
[10] O’rouke T D and Crespo E 1988 Geotechnical Properties of Cemented Volcanic Soil Journal of Geotechnical Engineering 114