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Finite Element Simulation to Determine Tree Safety Factor Using Geoelectrical Mapping as an Input

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Abstract. The distribution of stress and strain of the root in the ground can be used to determine the stability of a tree. The distribution itself is affected by the root architectural factor, the shear and tensile strength of ground and tree, and the geometry. The root architectures are mapped using geoelectrical method. In this method we use dipole-dipole configuration. Geophysical data acquisition was carried out with 6 lines of 3 m length, 25 cm electrode spacing and radial orientation around the target tree to map the distribution of the secondary root, an also a line of 15 m length, 1 m spacing and east-west orientation to map the maximum depth of the primary root. This research is conducted in Lapangan Sipil of Institut Teknologi Bandung. Geophysical data inversion is done to get the root architecture. The geoelectric data processing is done using RES2DINV software. We obtain the shear and tensile strength of the ground from literature study. The inversion result and literature data are used as input to do finite element situation to get the distribution of stress and strain of the tree and the ground. Finally, the result of the simulation can be used to determine the safety factor of the tree in certain weather.

1. Introduction

The fallen tree in urban areas caused by a high accumulation of wind can be categorized as a disaster because it leads to injury or property damage, so the mitigation is needed. There have been several ways to determine the safety factor of the tree by pull test and dynamic test. In pull test method, tree is pulled to simulate moderate wind loading and the resultant changes in fibre length and root plate inclination are measured. The experiment is designed to determine how tree responds to define loads. Pull test gives and accurate result of the maximum resistive moment that can be produced [1], but this method may damage the tree. While dynamic test gives estimation of the expected wind load at a given location during a defined wind event from the measured strain value of the trunk [2]. However, this method does not accommodate the mechanical factor between the roots and the soil. In the end, the use of static pull tests is needed to calibrate the value of the tree's strength, so the measure of wind load can be obtained by converting strain readings into bending moment values.

This research is conducted to provide a non-destructive method using finite element simulation to give insight about stress and strain distribution on the soil which can be used to determine tree safety factor. We believe that root architecture is the key factor for tree stability due to uprooting, so we need to take root architecture into account in the safety factor determination. In this study, dynamic load factor from wind is not yet accommodated.

2. Data and Method

2.1 Data

Finite element simulation needs data inputs, including tree geometry, Poisson's ratio and young modulus. Poisson's ratio and young modulus data are obtained from literature study, which are Young Modulus of tree at humidity at 12% is 8000 Mpa and the Poisson's ratio 0.3, Clay Soil have Young Modulus of 14 Mpa and Poisson's ratio of 0.4 [3,4]. Tree geometry defined into tree radius and tree height, which values are respectively 0.4 m and 3 m. The soil in the field is assumed to be hard clay and has a yield strength of 1 MPa.

Root architechture obtained from geophysical survey using geoelectrical method. Geoelectric survey is conducted using 7 lines, namely 1 main line and 6 line short. Each line uses dipole-dipole configuration in figure. 1a. The primary line has a span width of 13 m and a space of 1m electrode with an east-west orientation. Other 6 secondary lines surround the tree with a 60^{o} azimuth spacing and span length 3 and a space of electrode 0.25m. This main line aims to obtain the maximum depth of the root and the short line to obtain a lateral root spread.

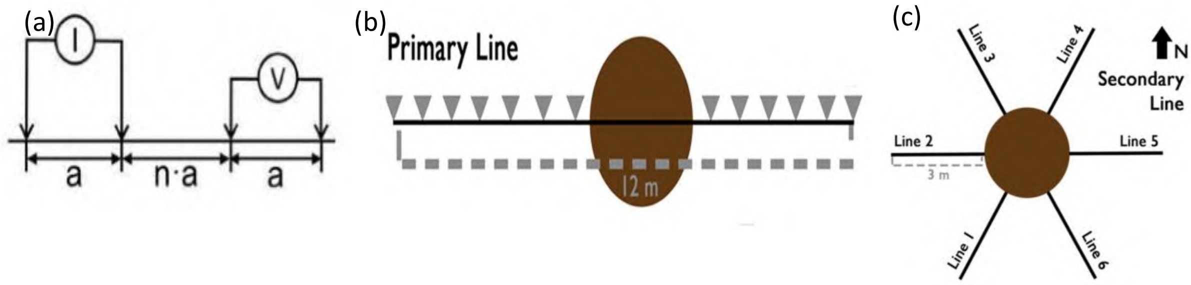

Figure 1. Illustration of line used in geoelectrical survey (a) Dipole-dipole configuration, (b)Primary line, (c) Secondary line consist of 6 lines spread around the tree target

2.2 Method

After geoelectrical survey is conducted, inversion is done using RES2DINV software to obtain the root spread image from geoelectrical data. Afterward, finite element analysis is done to obtain the stress and strain distribution on trees and soil. We use the FEATool Multiphysics Toolbox to perform finite element analysis [5]. The process in performing finite element analysis is input the tree geometry, define grid for finite element discretization, input the equation, input the boundary, and solve the equation.

After tree geometry input is done, we discretize it with tetrahedron-shaped element, this is the simplest form but required a detailed mesh [6]. In this case the maximum spacing of each node used is 0.2 m. The linear elasticity equation is used to approaching this problem. The equation expressing the relationship between stress and strain in each tetrahedron element can be expressed as follows:

$$\begin{pmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{xz} \end{pmatrix} = \frac{E}{(1+\nu)(1-2\nu)} \begin{pmatrix} 1-\nu & \nu & \nu & 0 & 0 & 0 \\ \nu & 1-\nu & \nu & 0 & 0 & 0 \\ \nu & \nu & 1-\nu & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1-2\nu}{2} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1-2\nu}{2} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1-2\nu}{2} \end{pmatrix} \begin{pmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{xz} \end{pmatrix} \quad (1)$$

E denotes the young elastic modulus, v is the Poisson's ratio of the material. To simplify finite element simulation, the tree is considered as a homogeneous and isotropic medium, and the mass of the tree is not considered. In order to solve this problem, boundary condition is needed. The boundary condition applied are no displacement on tip of the root and the external forces acting only at the top of the trunk. This boundary condition is relevant because before uprooting condition, the root tip has the least displacement value. If the tree is in a relatively flat area, the external force on the tree comes only from the wind and the maximum force is received at the top of the trunk.

After the equation is solved, we convert the stress value to principal stress value. From this principal stress we can determine the von misses stress with the equation below. The results of the Von Misses calculation is a property related to when the particular material starts to fail and yield plastically, instead of elastically.

$$\sigma_v = \left(\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_1-\sigma_3)^2}{2}\right)^{1/2} \quad (2)$$

The output of tis study is to determine the safety factor of tree due to uprooting in certain condition. We estimate the safety factor of the tree when force applied to simulate wind loading at given direction. If the von misses stress in the soil have same values as the yield strength in simple uniaxial test, then safety factor of the tree in that condition would be 1.

3. Result and Analysis

From these results, we can infer that root has resistivity value higher than its surrounding soil. It is indeed determined by root's water content and its chemical composition. Figure 2 shows that root has resistivity value about 150-368 ohm.m, with RMS error value of 60%. High RMS error value because tree root has 3D configuration in the subsurface so the consequences is high lateral heterogeneity resistivity value. 2D resistivity method map subsurface with high lateral heterogeneity poorly, but it still can be used to estimate the root architecture. After tree and root geometry is obtained, the tetrahedron-shaped element is generated to discretize the object, as shown in figure 3.

For finite element simulation we input 50 kN force in the x positive direction at the tip of the stem, this give overturning moment about 150 kN.m. The simulation results give information about distribution about total displacement value, x strain direction and von misses stress. In figure 4 it can be seen that the soil strain behavior value is larger than the tree strain behavior value, red color refers to the positive strain (elongation), and blue is the negative strain (shortening). Figure 5 shows the expected result that the largest total displacement value occurs at the end of the stem because the input force works there. The von misses stress distribution can be used as an indicator of the safety factor of a material, since yielding starts when the maximum distortion in the material equals the maximum distortion at a simple tension test. It can be seen in figure 6 that the largest value of von misses stress on soil is about 1 MPa or equal to the yield strength of the soil, then the safety factor of the tree in this condition is 1.

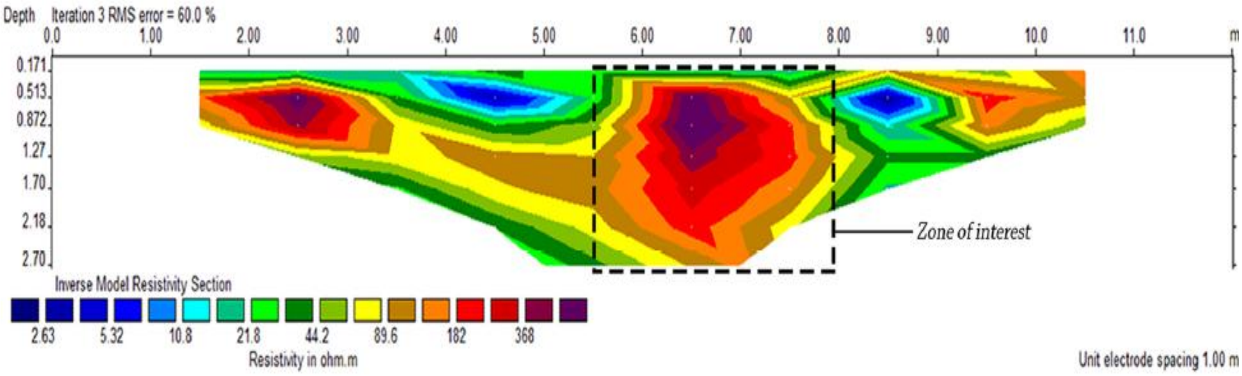

Figure 2. Inversion results for primary line using RES2DINV

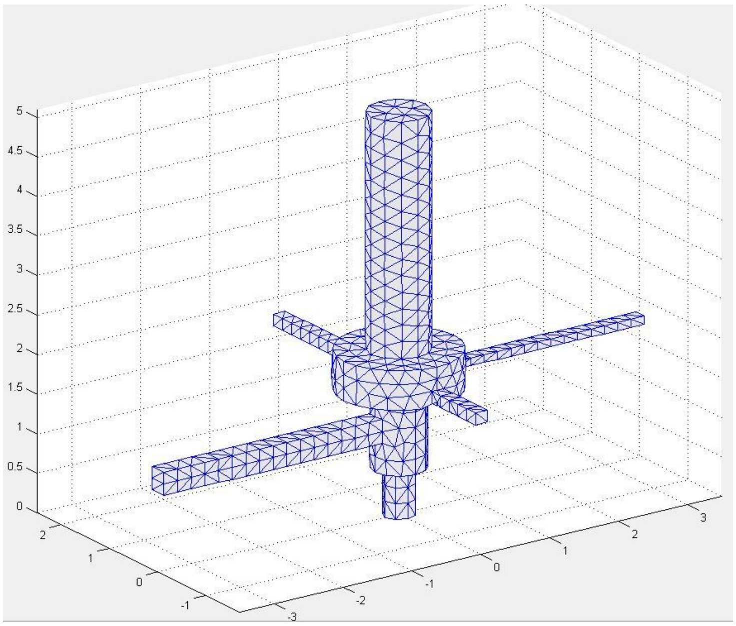

Figure 3. Tree geometry gridding

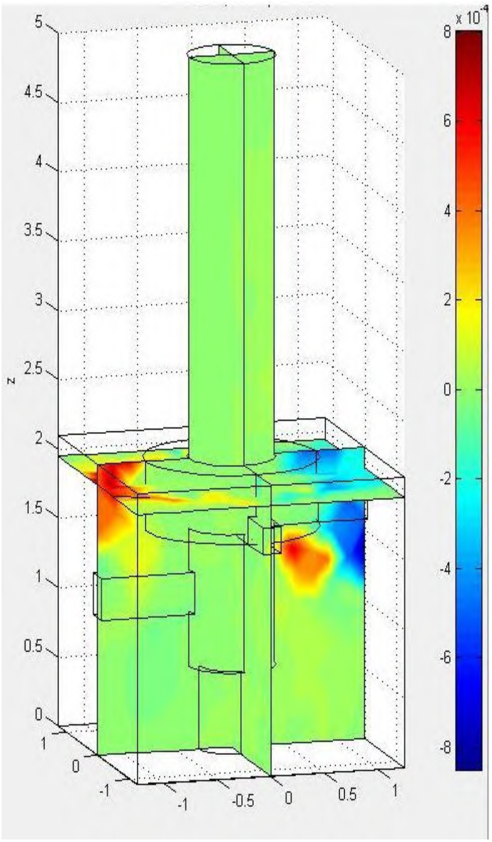

Figure 4. Strain distribution in X-direction

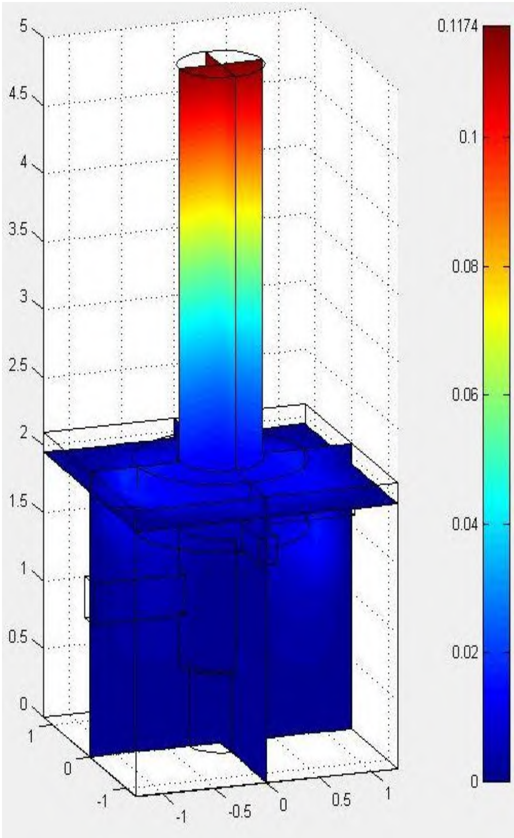

Figure 5. Total displacement distribution

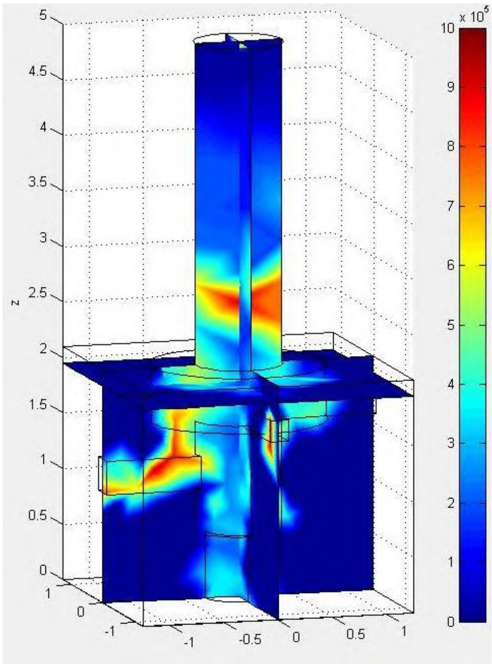

Figure 6. Von Misses stress distribution

4. Conclusion

Using finite element simulation, the stress and strain distribution on tree trunk and soil can be obtained. In this study we focus on determine tree safety factor due to uprooting. To determine the tree safety factor, it is necessary to map the tree root architecture, because soil stress is influenced by the root architecture. The 2D geoelectrical method map root architecture poorly due to the high lateral heterogeneity, which shown as high RMS error in geoelectrical inversion result. Von misses stress is used to determine the failure criteria of the tree, so we can estimate tree safety factor when stress is applied. The results illustrated the tree stress and strains distribution, but the model used is simplified. Thus, it needs further studying on applying wind stress to the tree and finite element assumption so that the tree geometry model used resembles the real condition

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