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Numerical simulations on electrical resistivity survey from tunnel face for multiple anomalies

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ABSTRACT

It is essential to identify subsurface obstacles ahead of tunnel to prevent accidents during tunnel excavation. In areas where underground utilities or foundations are present, the existence and position of such obstacles are of significant concern. Electrical resistivity surveys can be conducted from the tunnel face to investigate subsurface conditions, even when surface structures such as building or pavement are present. This study performs a parametric analysis using a numerical model to examine how the positions of multiple anomalies influence the electrical resistivities obtained from electrodes installed at the tunnel face. The results contribute to identifying which parameters have the most significant impact on the resistivity response, thereby supporting improved detection and interpretation of subsurface anomalies.

1. INTRODUCTION

Electrical resistivity survey measures electrical resistance between the electrodes penetrating the ground surface. The resistivity of the ground is retrieved as the characteristic of the site. Applications such as large-scale survey for hydrogeological investigations of the subsoil, prospecting for resources (Lech et al., 2020), and detection of structural features underground (Kim et al., 2024).

Electrical resistivity survey measures the apparent electrical resistance between the electrodes penetrating the ground by applying potential differences and measuring the induced electrical flow between them. There are various ways to determine the resistivity distribution of the medium, ERT(Electrical Resistivity Tomography) being one of the major application. (Ryu et al., 2017) developed TEPS(Tunnel Electrical

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Resistivity Prospecting System) to locate underground structures such as fracture, spherical anomaly, and underground utility using the analytical expression of resistivity for certain types of anomaly, and performing inverse analysis to determine the unknown geometrical parameters of the underground structures.

This research is a sensitivity study through numerical analysis to investigate how the geometric parameters of the underground structure influence the measured resistance.

2. LITERATURE REVIEW

Electric resistivity is an intrinsic property of a material identifying how strongly it resists electrical flow. Electrical resistance reflects the geometry of the material, and can be measured through field survey.

2.1 Electrical constitutive equations

Electrical resistivity can be derived from Ohm's law and Maxwell equations. By writing the Ohm's law using current density J and electric field strength E, the conservative charge can be expressed with the following equation.

$$\nabla \cdot J = Q \tag{1}$$

The current density and the potential distribution can be expressed with Eq. (2) and (3)

$$J = \sigma E + J_e \tag{2}$$
$$E = -\nabla V \tag{3}$$

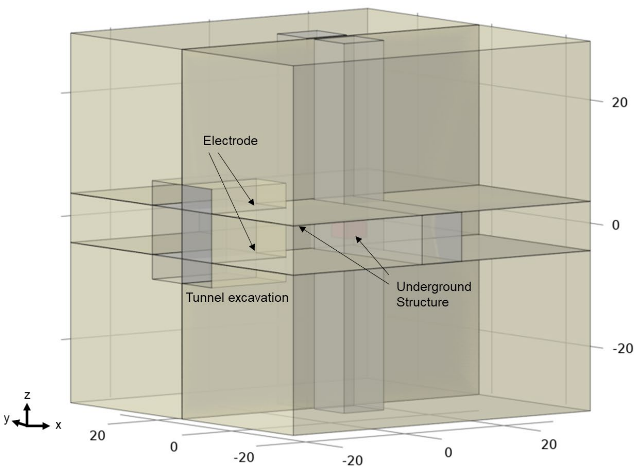

Fig. 1 Model geometry for excavated tunnel front

3. NUMERICAL MODEL

Finite element method with COMSOL Multiphysics® is used to model the electrical resistance reflecting the geometry of the tunnel front. The model reflects the characteristics of a simplified tunnel, and have two electrodes with fixed distance embedded at the center of the tunnel front. The shape of the electrodes is cylindrical with a conical tip. Cases with different distance between the cubic anomalies and from the tunnel face are built.

3D meshing techniques from (Kim et al., 2024) and (Rye et al., 2025) are employed, using mapped and swept functions to produce relatively accurate electrical resistance by numerical analysis. Constitutive equations for the electric current flow, including charge conservation, electrical current density distribution, and electric potential (Eq. (1), (2), and (3)) are used to model the stationary state.

4. CONCLUSIONS

This research developed a simplified model for an excavation and the electrical resistance for a case study of double anomalies. The results show the measured resistance from the electrodes with each case.

The results contribute as the preliminary sensitivity analysis for identifying and deciding which geometrical parameters describing the underground structure in the tunnel front shall be further investigated.

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