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論文題目	Three-dimensional stress measurement technique based on electrical resistivity tomography （電気抵抗率トモグラフィーに基づく三次元応力計測技術）		

（論文内容の要旨）

Geo-stress plays a crucial role in the design and construction of underground excavations. It is a significant factor in designing slope protection, controlling settlement, and tunnel boring, as well as an essential safety indicator during construction. This study proposes a three-dimensional stress measurement technique capable of directly determining the stress tensor, which uses the electrical resistivity tomography (ERT) conductivity reconstruction technique, coupled with conductive rubber. ERT is a non-destructive technique that can infer the inner conductivity distribution from the voltage measurement conducted between the surface electrode. By applying the ERT conductivity reconstruction technique, conductive rubber that obeys the piezoresistive law can be used for pressure distribution measurement. When pressure is applied to the conductive rubber, the rubber deforms and its conductivity distribution changes; thus, the conductivity change could be monitored with ERT and converted to stress distribution based on the mechanical properties of conductive rubber. Experiments using the shield face visualization apparatus and centrifuge model test machine were performed to validify the applicability of the sensor.

Chapter 1: Introduction
The research background of geo-stress measurement and the motivation to develop the 3D stress sensor are introduced. The structure of thesis is briefly summarized.
Chapter 2: Literature Review
The development and current state of geo-stress measurement, electrical resistivity tomography and ERT-based stress sensor are reviewed.
Chapter 3: DEM simulation of cylindrical geo-sensing prototype
An electrical contact theory-based geo-sensing prototype is introduced. DEM simulation was performed to find out the relationship between mean stress distribution and contact area to verify its applicability.
Chapter 4: Electrical resistivity tomography
The physical model and algorithm of ERT conductivity reconstruction are presented. The data acquisition protocol for voltage measurement between the electrode is specified, and the process of transforming the voltage dataset into a conductivity distribution is introduced.
Chapter 5: Multi-directional stress sensor
The hardware of stress sensors is introduced, which possess wireless automatic and real-time measurement functions. The raspberry pi microcomputer is used to control the circuits and measure the voltage based on the stimulation and measurement pattern.

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Chapter 6: Preliminary experiments using planar rubber sensor

Preliminary tests using the planar rubber sensor were conducted to study the basic characteristics of the ERT-based rubber sensor. The ERT-based rubber sensor can effectively detect the loading area and location. The average conductivity of the rubber sheet is negatively correlated with the load and deformation. The time-dependent hysteresis is induced by the viscoelastic characteristics of the conductive rubber, and the hysteresis effect impacts the accuracy of the sensor.

Chapter 7: Stress measurement using hemispherical rubber sensor

The seventh chapter demonstrates the three-dimensional stress measuring ability of the hemispherical rubber sensor. Experiments are carried out using the shield face visualization apparatus with the hemispherical rubber sensor inside. The uniform water pressure test and uniform earth pressure test are conducted to reveal the relationships between the average conductivity and mean stress as the calibration method. Three prevalent projection methods between 2-dimension and 3-dimension are concluded, and an experiment is used to choose the most adequate projection method. The excavation experiments in the soil are performed to verify the stress measuring ability of the hemispherical rubber sensor. The relationship between peak value of average conductivity and shear strength of soil is discussed. Two stress tensor determination methods are presented.

Chapter 8: Stress measurement using cylindrical rubber sensor

The eighth chapter shows the test results of the cylindrical rubber sensor. The cylindrical rubber sensor is calibrated using uniaxial compression test. The centrifuge tests are conducted to confirm the stress measuring capacity of the cylindrical rubber sensor. A stress determination method is proposed to find the maximum and minimum principal stress.

Chapter 9: Conclusions

This study presents a novel approach to 3D stress measurement in geotechnical engineering, utilizing ERT-based conductive rubber sensors. While previous ERT-based sensors have primarily focused on planar pressure mapping, this research develops hemispherical and cylindrical conductive rubber sensors and corresponding 3D stress tensor determination methods. The reconstructed conductivity distribution image can provide distinct and intuitive stress magnitude and direction information. By the stress tensor determination methods, the comprehensive 3D stress tensor can be obtained using one device and one measurement which is not realized by the other sensors. The effectiveness of the ERT-based rubber sensors was experimentally validated in geotechnical experiments, demonstrating their capability in measuring the stress state. These sensors provide a comprehensive measurement scheme of the stress state and potentially increase reliability and safety in construction, design, and management.

Appendix A: Mathematical model, boundary condition and complete electrode model

Appendix B: Linearized inverse solution based on Gauss-Newton method