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EDITORIAL BOARD (NEW)

Research Highlights

Korea Advanced Institute of Science and Technology (KAIST), South Korea

The Geotechnical Engineering Division in Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology (KAIST) is one of the most productive groups of its kind in the world. Our faculty members are internationally recognized experts in various sub-disciplines within geotechnical engineering. Currently, our division consists of 4 faculty members, over 40 graduate students, 3 postdoctoral research fellows, 3 research associates, 3 technical support staffs, and 3 administrative support staffs. KAIST is the one of the prestigious research-oriented schools, ranked 41 in the QS World University in 2018, and the department is ranked in the top 15 in its sub-discipline owing to its strong academic reputation and high number of citations per faculty member.

Faculty Members

Dr. Seung-Rae Lee, Professor

Dr. Seung-Rae Lee is a professor at the Dept. of Civil and Environmental Engineering at KAIST. He joined KAIST in 1989 and has since made significant contributions to establishing the Geotechnical Engineering Division at KAIST by setting up the curriculum and supervising a number of graduate students. Dr. Lee served as an editorial board member of several international journals, including Computer and Geotechnics and Acta Geotechnica. He has published more than 150 journal papers and 124 conference proceedings, and participated in many research projects as a principal investigator over the last 25 years. His current research includes geothermal

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energy recovery and heat storage, early warning system and prevention of landslide disasters, and design of radioactive waste disposal system. Recently he has dedicated himself as a chief investigator of the research center of extreme rainfall-induced landslide (ERL) from 2012 to 2017, aiming to develop a real-time prediction and counterplan system of landslide disaster.

Dr. Dong-Soo Kim, Professor

Dr. Dong-Soo Kim is a professor at the Dept. of Civil and Environmental Engineering at KAIST and the director of the KOCED Geo-Centrifuge Center. His primary field of expertise is site characterization, seismic design of geotechnical structures, and geotechnical centrifuge tests for earthquake and offshore geotechnical issues. Dr. Kim served as an Associate Vice President of Research and a Director of Applied Science Research Institute at KAIST. Currently, he is serving as an editorial board member of the journal Géotechnique Letters, vice president and a board member of the Korean Geotechnical Society, Earthquake Engineering Society of Korea, Korean Geo-Environmental Society, and Korea National Committee on Large Dam. He was the General Secretary of the 5th International Symposium on Deformation Characteristics of Geomaterials, and the Chairman of the 19th International Conference on Soil Mechanics and Geotechnical Engineering. (19th ICSMGE-Seoul).

Dr. Gye-Chun Cho, Professor

Dr. Gye-Chun Cho is a professor at the Dept. of Civil and Environmental Engineering at KAIST and the director of the Center for Utility Tunnel (CUT), which is dedicated to developing core technologies for the design, construction, and maintenance of urban small-diameter utility tunnels. His main research includes biopolymer treatment for soil improvement, geophysical characterization of geo-materials, design and construction methods for tunnels and underground spaces, geotechnical solutions for urban regeneration, and energy-related geotechnology, including gas-hydrate bearing sediments and geologic carbon dioxide storage. He has published more than two hundred international journal and conference papers. Dr. Cho and his group are actively engaged in collaborative research with various researchers from the Korea Institute of Civil Engineering and Building Technology (KICT), Korea Institute of Geoscience and Mineral Resources (KIGAM), Korea Electric Power Research Institute (KEPRI). and other research institutes.

Dr. Tae-Hyuk Kwon, Associate Professor

Dr. Tae-Hyuk Kwon is an associate professor at the Dept. of Civil and Environmental Engineering at KAIST. His research interests lie in emergent bio-thermo-hydro-mechano-coupled processes in subsurface, related to energy and sustainability problems. His current research centers on methane hydrate, geologic carbon storage, energy resource recovery, microbial activities in geo-materials, and landslides and debris flows, with novel multiscale experimentation involving geophysical characterization and process monitoring (both elastic and electromagnetic waves), X-ray CT imaging (both pore- and core-scales), and related inverse problems. He is also serving as an associate editor of International Journal of Geo-Engineering and Journal of Korean Society of Hazard Mitigation.

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Current Research

1. Landslide hazard, geothermal energy, high-level radioactive waste disposal

The research activities in which Dr. Seung-Rae Lee and his group are engaged are further described as follows:

High-efficiency ground heat exchanger systems: Low-cost and high-efficiency ground heat exchanger systems were developed to utilize geothermal energy. A heat exchanger system consists of (i) laboratory experiment and numerical analysis for developing heat transfer models for various heat exchangers, and (ii) thermo-hydro-mechanical analysis for heat transfer mechanisms of standing column wells considering ground water flow. As a result of his research, a robust geothermal energy design program and a numerical modeling code for standing column wells was developed, which was the first in Korea, enabling the optimal design of horizontal heat exchangers.

Landslide early warning system: A landslide early warning system was developed and is in operation for mitigating landslide hazards that frequently occur in Korea by taking into account the geological, topographical, geotechnical and rainfall characteristics. The developed landslide early warning system consists of (i) statistically-based landslide-induced rainfall thresholds and a landslide susceptibility map for estimating temporal and spatial probability, (ii) physically-based continuous rainfall thresholds derived from a slope stability analysis considering the rainfall infiltration mechanism, (iii) debris flow initiation criteria developed from a geomorphological evaluation technique for deciding whether the hazard type is from slope failures or debris flows, and (iv) a numerical modelling of debris flow impact factors for estimating potential hazard and risk information. The system is currently in operation for Busan, the second largest metropolitan city in Korea.

High-level radioactive waste disposal: The thermo-hydro-mechanical characteristics of bentonite buffers, one of the important components in deep geologic disposal of high-level radioactive wastes, are currently investigated. Through this study, they aim to propose an optimal temperature and temperature range in which buffers satisfy basic performance requirements. They strive to solve social issues in Korea through the aforementioned research studies.

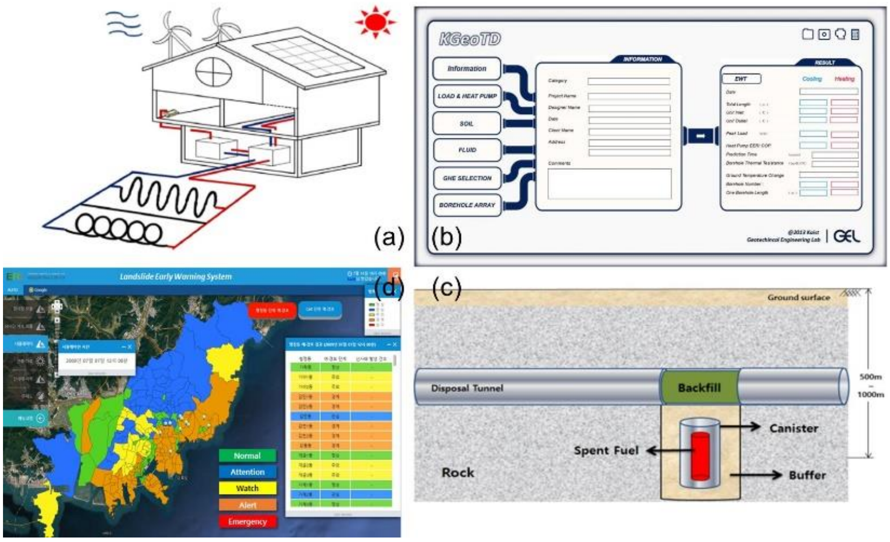

Figure 1. (clockwise from top left) (a) a schematic diagram of horizontal ground heat exchangers, (b) the developed geothermal energy design program, (c) a deep disposal system of high-level radioactive wastes, and (d) the developed landslide early warning system in operation.

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2. Seismic-related issues

Dr. Dong-Soo Kim and his research group are actively researching earthquake and seismic-related issues. Examples of their research projects are as follows:

Rocking foundation: the use of the rocking behavior of a shallow foundation, called rocking foundation, has emerged as an effective seismic design of shallow foundation to reduce the seismic load on super-structures. The rocking mechanism for the embedded shallow foundation is investigated with an emphasis on (1) soil rounding effect on embedded shallow foundation via horizontal slow cyclic tests; (2) comparison between cyclic and dynamic rocking behavior for embedded shallow foundation considering structural flexibility; (3) centrifuge modeling of improved design for rocking foundation using short piles.

Gravity type quay wall: To apply the performance-based design to a quay wall, the seismic performance verification methods for quay wall were improved. The detailed aspects of quay wall design are described as follows: (1) improvement of a seismic coefficient for limit-equilibrium-based design; (2) improvement of a seismic coefficient for performance-based design; (3) verification of performance of gravity type quay wall using a centrifuge test with viscous fluid; (4) evaluation of the dynamic earth pressure on a cantilever retaining wall.

Liquefaction: To analyze the liquefaction problem in detail, the physical and numerical modeling of the liquefaction is important. Liquefaction experimental and analysis projects (LEAP) is a global project to simulate the liquefaction of the ground by physical and numerical modeling. The soil dynamics laboratory at KAIST, additionally, participated in the LEAP (2016). The detailed aspects of liquefaction are described as follows: (1) development of centrifuge testing system for liquefaction phenomena; (2) development of Korean guidelines for identification, assessment, and mitigation of liquefaction hazards.

Site response analysis: The evaluation of seismic force on a structure is an essential part of the seismic design procedure. The seismic force depends on geological factors and hence, site characterization and estimation of soil amplification are needed to accurately evaluate the seismic force on a structure. However, the current seismic design code of Korea is based on the seismic design code of western US, without considering ground conditions relevant to Korea. In this study, a new seismic site classification system and site amplification factors were developed by considering the local ground conditions in Korea and design response spectra were proposed for different soil conditions. The new seismic design provisions were recently approved to be included in the revised version of the Korean national seismic design code. The detailed aspects of site response analysis are described as follows: (1) improvement of Korean seismic design code for the site classification system and site coefficient; (2) site response analysis and verification based on the field data.

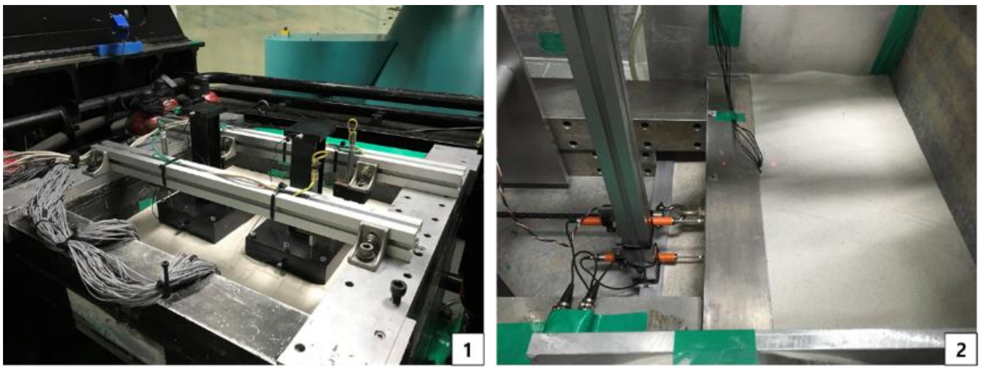

Figure 2. Geotechnical centrifuge test setup for earthquake related issues. (1) seismic behavior of single degree of freedom structure on disconnected piled raft (DPR); and (2) gravity-type quay wall.

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3. Offshore foundation-related issues

Dr. Dong-Soo Kim and his research group also investigate geotechnical engineering problems and technologies related to offshore foundations. Examples of their research projects are as follows:

Suction bucket/bucket installation: Offshore structures use skirted foundations or large diameter piles because offshore structures should withstand the huge environmental loads that are dominated by horizontal and overturning moment loads. The suction bucket is being considered as a competitive foundation type for offshore structures because underwater installation allows the use of 'suction' to help installation of suction bucket. The detailed aspects of suction bucket are described as follows: (1) suction bucket installation response; (2) bearing capacity of bucket foundation under uniaxial load; and (3) pullout resistance of suction bucket.

Lateral behavior of monopile: A large-diameter monopile foundation is favorable for non-cohesive soil layer with shallow bedrock depth. On a typical offshore wind turbine (OWT), the structure would be subjected to wind, waves, and current loads, and this combined load will apply overturning moments at foundation level. Therefore, the design of offshore foundation to support a wind turbine involves greater technical challenges, and the foundation must be designed to survive large horizontal and overturning loads. The subject of monopile lateral behavior covers: load-displacement behavior of large diameter monopile.

Dynamic behavior of offshore wind turbine: Dynamic behavior evaluation of the offshore wind turbine (OWT) is required to design the structure to avoid vibration-induced damage such as resonance or seismic behavior. As the dynamic behavior of a structure is affected by soil-foundation-structure interaction (SFSI), this research focuses on evaluating natural frequency reduction because of the SFSI, and seismic behavior during/after the earthquake considering SFSI. The detailed subjects for OWT dynamic behavior are described as follows: (1) evaluation of OWT natural frequency; (2) seismic response of OWT.

Cyclic behaviors of tripod foundation: This involves the evaluation of the cyclic behaviors of the tripod foundation supporting the offshore wind turbine. Recently, the use of tripod suction bucket foundation is rapidly expanding as a foundation system supporting offshore wind turbines. In the offshore environment, wind turbine foundation structures should be designed by considering cyclic loading, which can lead to permanent deformation of structure, tilting problem, and overall degradation of soil stiffness. By using the centrifuge and 1-g model tests, cyclic behaviors can be evaluated. Cyclic behaviors depend on various loading characteristics, loading direction, level, and rate, and these were controlled for the investigation of cyclic behaviors of the tripod foundation. The detailed aspects of tripod foundations are described as follows: (1) permanent displacement of foundation; and (2) cyclic stiffness response of tripod suction foundations.

Submerged floating tunnel (SFT) foundation: Standardization of design and analysis protocols for anchorage-foundation systems considering the submerged ground condition are critical. This research shall focus on developing core technologies needed for the construction of smart submerged infrastructure of the highest standard globally, ensuring smartness, safety economic-viability and construction-ability. The detailed aspects of SFT foundation systems are described as follows: (1) foundation-anchor system for supporting submerged floating tunnel; (2) foundation design considering submerged ground condition; (3) assessment of foundation system behavior under various loading conditions.

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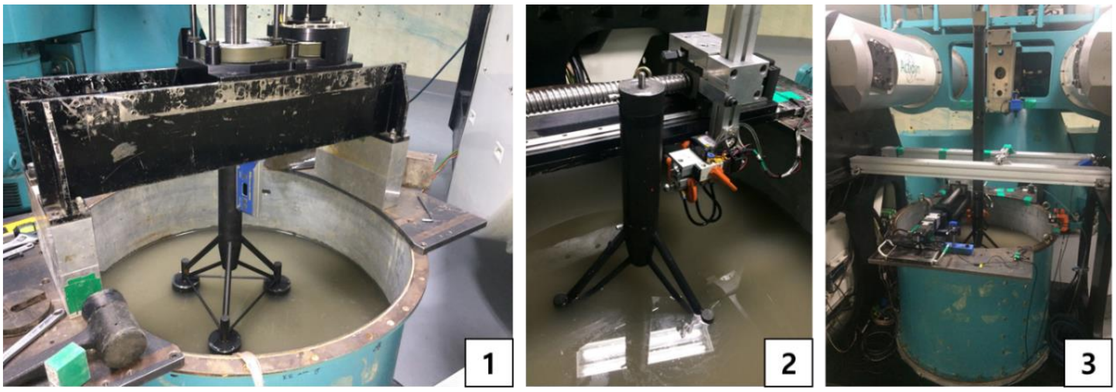

Figure 3. Geotechnical centrifuge experiment procedure for tripod offshore wind turbine's dynamic behavior evaluation. (1) foundation installation using vertical actuator; (2) impact test setup for evaluating OWT natural frequency; and (3) finished geotechnical centrifuge test setup

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4. Soil treatment and monitoring related issues

Dr. Gye-Chun Cho and his research group are engaged in the following research activities:

Biopolymer-treated soils: Biopolymer treatment of soils can provide an eco-friendly and cost-effective alternative as a soil binder. Biopolymers are polymers derived from biological origins and have been used in various industries such as medicine, food, and agriculture. Various biopolymers such as chitosan, beta-glucan, xanthan gum, agar gum, and gellan gum are mixed with various soil types to investigate soil-biopolymer interactions and related soil-strengthening mechanisms. In addition to laboratory testing, field tests on soil slopes and soil pavements for erosion prevention were conducted, and the results verified the effects of biopolymer treatment.

Underground space monitoring: The construction of underground structures requires extensive monitoring of geological conditions. The sudden appearance of abnormal ground conditions can result in the collapse of the excavation face, which can have disastrous effects. Therefore, it is necessary to predict the ground conditions ahead of the excavation face. The tunnel electrical resistivity prospecting system (TEPS) developed by Dr. Cho's group can predict the ground conditions ahead of the excavation face using electrical resistivity techniques. The system can estimate the rock mass classification (RMR or Q-value), location, size, and status of any anomalies lying ahead of the tunnel face.

Gas hydrates and geologic carbon dioxide storage: Gas hydrates found in onshore permafrost sediments or offshore marine sediments are a potential future energy source. Gas hydrate-bearing formations can be also used as a cap-rock during carbon dioxide storage in marine sediments, where the byproduct hydrates form an impenetrable layer above the gas storage site. In Dr. Cho's group, both scenarios are investigated using experimental and numerical analysis techniques. Using seismic wave velocities and electrical resistivity techniques, the effects of hydrate formation and dissociation in various types of sediments are investigated. The "KAIST-Hydrate" program can also successfully model 2D and 3D multiphase T-H-M coupled analysis for hydrate production and well stability, as well as settlement, volumetric strain, shear stress, and hydrate saturation.

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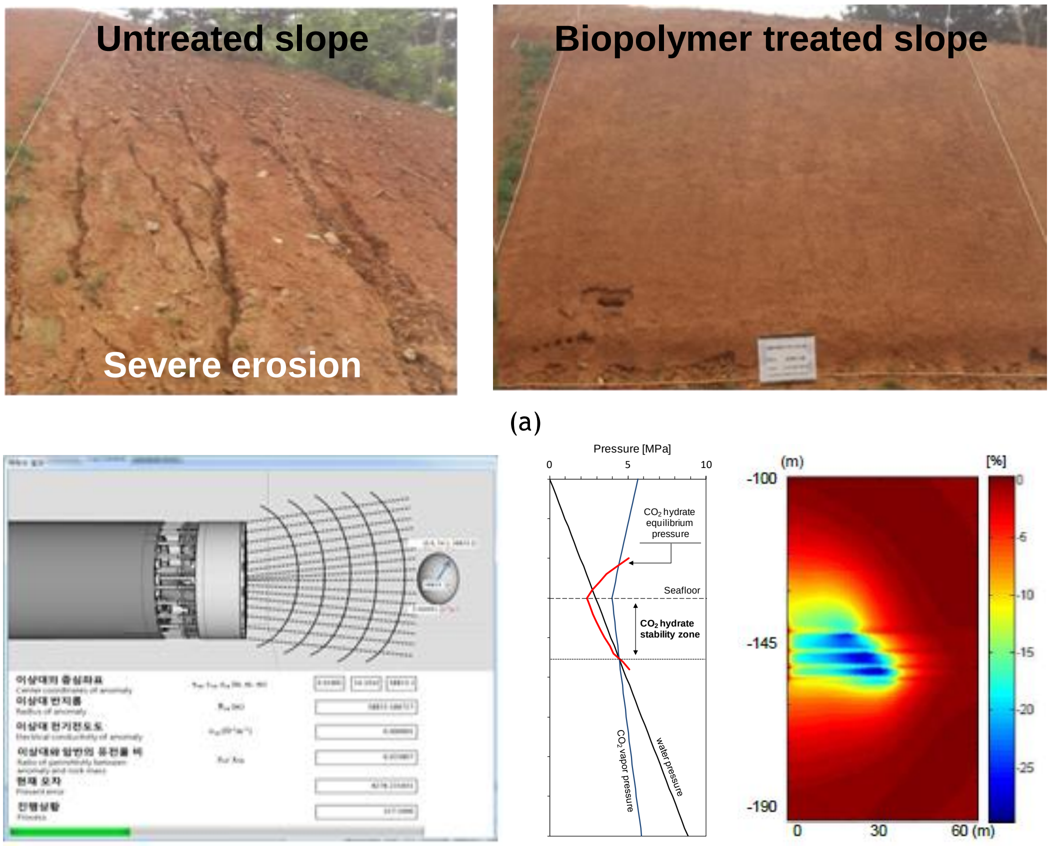

(a)

(b) (c)

Figure 4. (a) Application of biopolymer-treated soils for slope stability and erosion prevention, (b) Developed tunnel electrical resistivity prospecting system (TEPS), (c) Developed numerical simulator for gas hydrate production and carbon dioxide sequestration

5. Excavation-related issues

Dr. Gye-Chun Cho leads research initiatives to bring together the academia, industry and government agencies to find sustainable solutions for various urban excavation and tunneling problems as follows:

Abrasive waterjet for rock excavation: Abrasive waterjet technology can be used to cut a rock alone or in conjunction with conventional mechanical excavation methods for rock excavation projects. The abrasive waterjet can remove the target material through the impact of abrasive particles accelerated by liquids flowing at high speeds. Dr. Gye-Chun Cho and his group have conducted research using different abrasives ranging from crushed garnets to steel balls and numerous water jet parameters have been analyzed both experimentally and numerically. Field studies using a prototype waterjet have yielded low vibration and low noise rock excavation with a clear excavation surface compared to conventional drill and blast techniques.

Center for Utility Tunnel (CUT): The Center for Utility Tunnel (CUT) is a government-funded research consortium of more than 34 universities, research institutes and industrial companies dedicated to developing core technologies for the design, construction and maintenance of urban small-diameter utility tunnels. CUT is one of the central components of Dr. Cho's research activities that drives the fundamental and applied research for the Korean tunneling industry.

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The main research projects conducted by the center include: (1) cross-section optimization and global standard design (LRFD) of utility tunnels; (2) life-cycle dependent safety management; (3) excavation rate prediction, propulsion and segment lining design of small diameter shield TBMs; (4) rapid construction techniques in special ground conditions; (5) noise- and vibration-controlled rapid excavation of vertical shafts; and (6) tunnel-shaft joint reinforcement and water cut-off systems.

The research project utilizes new and existing technologies for application in urban tunneling. These technologies include abrasive waterjet schemes for low vibration rock excavation, biopolymer grouts for shaft reinforcement, and electrical resistivity techniques for tunnel-ahead prediction. The center aims to build upon current research in geomechanics and excavation, and develop further expertise in the application of these technologies to urban tunneling and underground space regeneration.

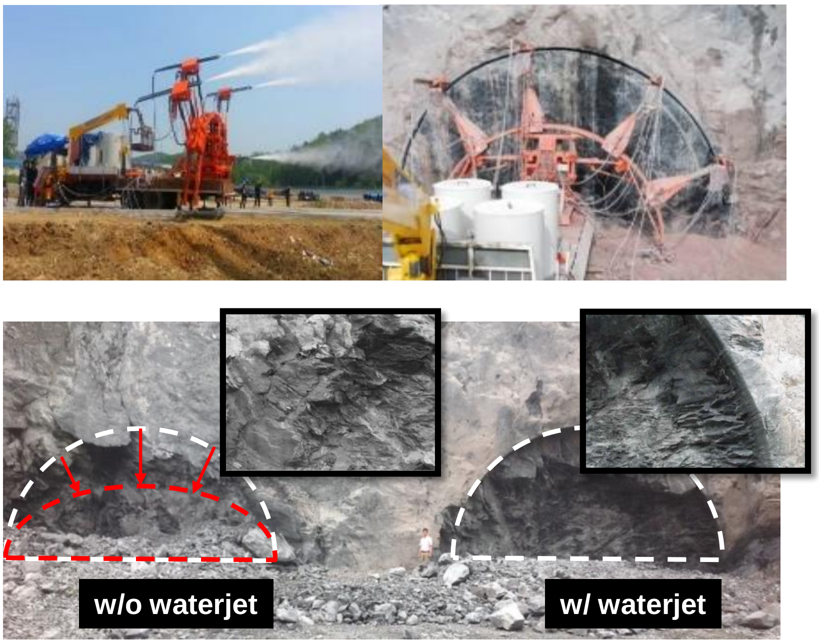

Figure 5. Application of abrasive waterjet for rock excavation

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6. Use of microbial activities in soil improvement

Owing to the growing interests in sustainability, significant interest is being garnered in soil and ground improvement methods using microbial byproducts (e.g., biopolymer and biofilm). Dr. Tae-Hyuk Kwon investigates engineering behaviors of soils associated with microbial activities, and examples of his research projects are as follows:

Bioclogging and erosion resistance improvement by bacterial biopolymer and biofilm formation: When the biopolymer-producing bacteria are cultivated in soils, the soft biopolymer can reduce hydraulic permeability by several orders of magnitude, thereby occluding pore spaces. In addition, erosion resistance of soils is also proven to be improved with the accumulation of biopolymers' coating and gluing soil grains together.

Viscoelastic characteristics of bacterial biopolymers: To predict the behaviors of biopolymer-associated soils, the behaviors and properties of the biopolymers must be identified because they are required as part of the effective mixture models. Dr. Kwon's group has been working on measuring the microscale elastic modulus and complex shear modulus of biofilms and biopolymers using atomic force microscopy (AFM) and particle-tracking microrheology (PTM).

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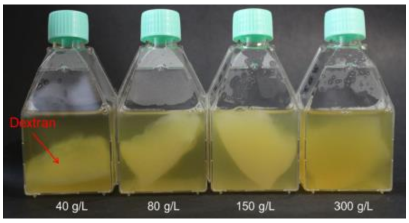
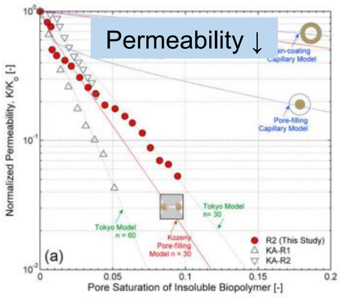
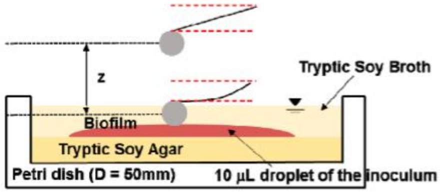
Seismic and induced polarization responses of bioclogged soils: Dr. Kwon and his group also investigate feasibility of using seismic responses (P and S wave velocity and attenuation) and induced polarization responses (complex conductivity) for monitoring *in situ* accumulation of bacterial biopolymers in soils. It has been found that biopolymer formation and the resulting permeability reduction can be effectively monitored by using P and S wave attenuation and by imaginary conductivity.

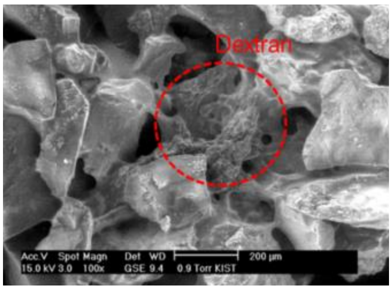


▲ Dextran grown aerobically

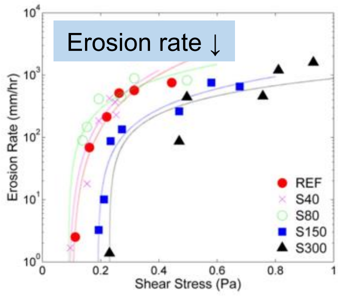


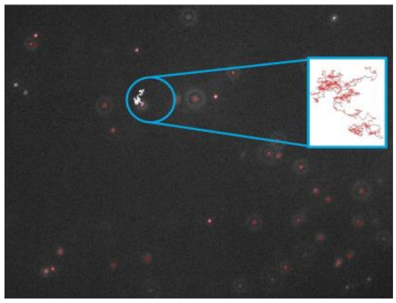


▲ AFM (Elastic modulus)



▲ Insoluble biopolymers





▲ Micro-rheology (Shear modulus)

Figure 6. Behaviors of biopolymer-accumulated soils.

7. Multiphase flows in porous media

Understanding, prediction, and manipulation of multiphase flows in porous media are some of the important challenges in various energy-related practices such as hydrocarbon resource recovery, energy storage, geologic carbon storage, and methane hydrate production. Examples of such research from Dr. Kwon's group are listed below.

Understanding and predictive modeling of multiphase flows in porous media: Various factors such as capillary number, viscosity ratio, and wettability affect multiphase flows. The fundamentals of multiphase flows in porous media are being investigated via microfluidics, pore network modeling (PNM), and computational fluid dynamics (CFD).

Microbial enhanced oil recovery: The effect of bacterial biosurfactant on enhancing oil recovery is studied by identifying the changes in interfacial tension (IFT) and contact angle during production of biosurfactant by bacteria.

Methane hydrate production: Methane production from natural hydrate-bearing deposits poses various challenges and problems related to seafloor stability, geohazards, and wellbore integrity. Therefore, the emergent phenomena occurring during dissociation of methane hydrate in sediments are being investigated via laboratory experiments using X-ray CT imaging and T-H-M-coupled numerical modeling.

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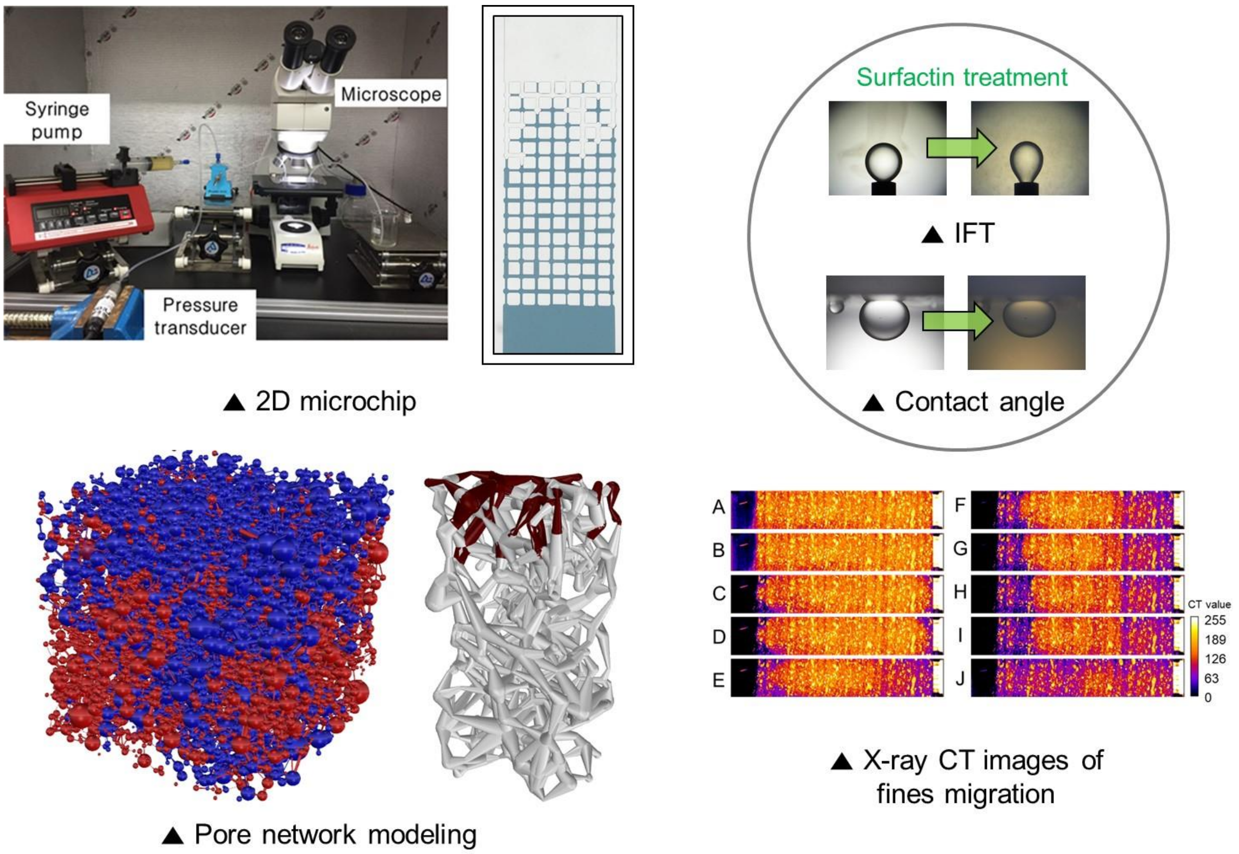

Figure 7. Research related to multiphase flow behaviors in porous media.

Research Facilities

State-of-the-art Geotechnical Centrifuge

KOCED's Geotechnical centrifuge testing center is equipped with the second largest geotechnical centrifuge facility in South Korea. This facility houses a geotechnical centrifuge having a 5-m radius arm with a 4.5 m effective radius, and a maximum capacity of 240g-ton. It has a flat basket with a dimension of 1.2 m × 1.2 m × 1.2 m (width × length × height). Additionally, it can be equipped with a centrifuge-mounted self-balanced earthquake simulator (shaking table).

Figure 7. KOCEDs geotechnical centrifuge

Manufacturing company	ACTIDYN systems (France)
Platform radius	5.0 m
Max. capacity	240g-tons
Max. payload	2,400kg up to 100g
Payload dimension	1.2 m × 1.2 m × 1.2 m
Max. acceleration	130g @ 1,300 kg payload

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The self-balanced earthquake simulator can generate sinusoidal and real recorded earthquake motions during experiments. It can take loadings up to 0.5g in prototype scale. The allowable frequency range of input load is from 20 Hz to 300 Hz on the model scale.

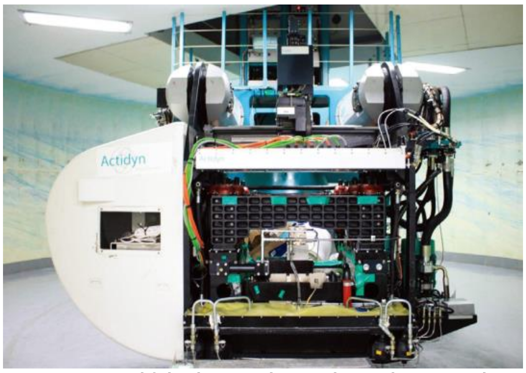

Figure 8. Self-balanced earthquake simulator

Electro-hydraulic servo type	
Max. payload	700 kg
Max. acceleration	0.5g (in prototype)
Frequency range	Max. 300 Hz
Platform dimensions	0.7 m × 0.7 m × 0.65 m

KOCED's Geotechnical centrifuge center has striven to build top-tier facilities to support geotechnical researchers, engineers and other construction companies. This facility has immense applicability to a wide variety of geotechnical problems including earthquakes and offshore engineering issues.

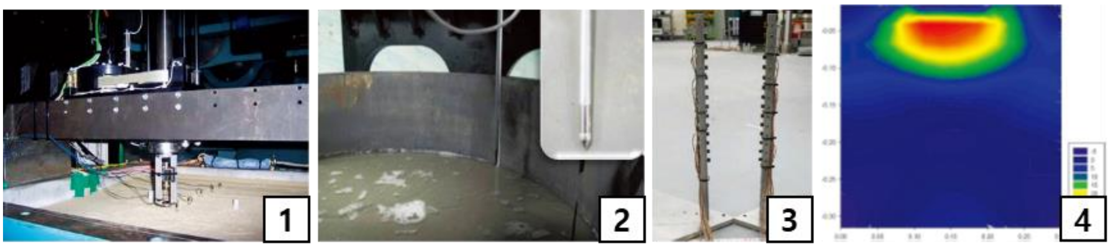

Figure 10. Soil property evaluation technique. (1) HWAW, SASW; (2) CPT; (3) Bender element array; (4) Tomography.

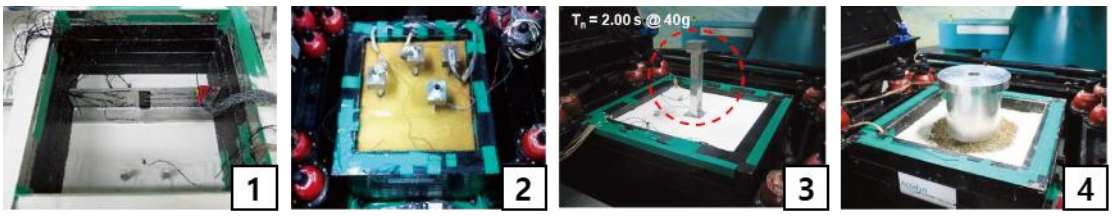

Figure 11. Seismic behavior analysis. (1) inversed T-shape retaining wall; (2) pile foundation; (3) shallow foundation; (4) nuclear reactor foundation.

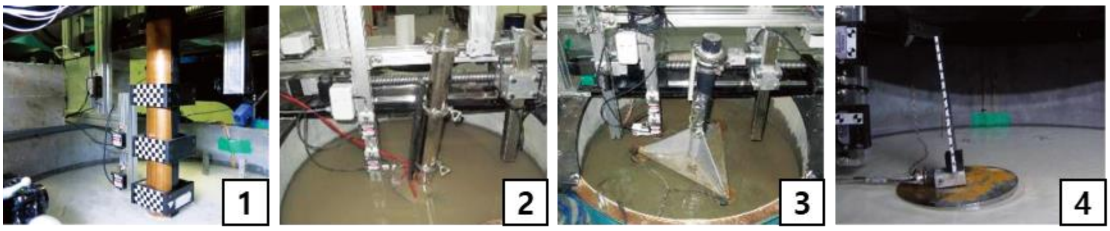

Figure 12. Offshore foundation evaluation. (1) monopile; (2) monopod; (3) tripod; (4) suction bucket foundation.

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Figure 13. Embankment seepage & settlement analysis.

Abrasive Waterjet System

The intensifier abrasive waterjet system is equipped with a hydraulic oil pump and intensifier that generates high water pressures. Abrasives are supplied to the high-pressure water near the end of the nozzle and the mixture is sprayed onto the target material via a focusing tube.

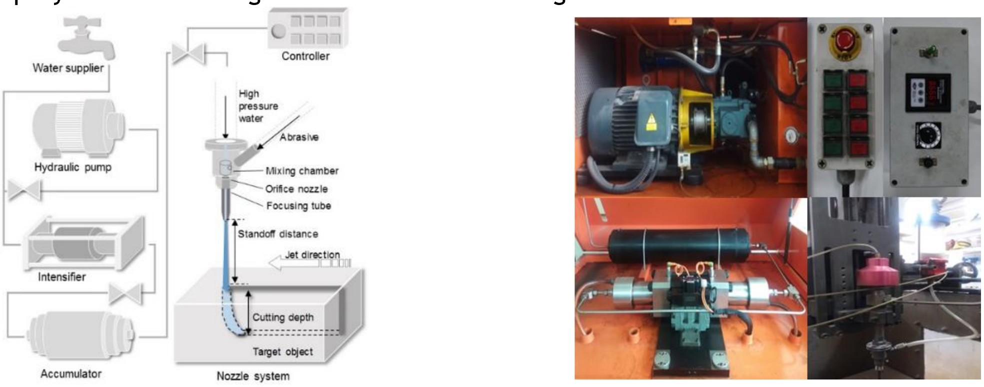

Figure 14. Abrasive waterjet system.

Max. pressure	420 MPa
Max. flow rate	6 L/min
Jet system	Sapphire orifice nozzle, Tungsten carbide focusing tube
Orifice diameter	0.254 mm
Jet transfer velocity	1.2–16 mm/s

Tunnel Electrical Resistivity Prospecting System (TEPS)

The TEPS system can predict ground conditions ahead of the excavation face using electrical resistivity techniques. More than five electrodes are necessary for accurate prediction of the tunnel face, and the system can measure a range of 3–4 times the tunnel diameter in the direction of tunnel excavation. A unique back analysis based on electrical field theory is used to calculate the electrical resistivity from the measured resistance.

Avg. measurement time	5 min
Avg. analysis time	30 min
Measurement range	3–4 times the tunnel diameter (in the direction of tunnel excavation)

Figure 15. Tunnel electrical resistivity prospecting system.

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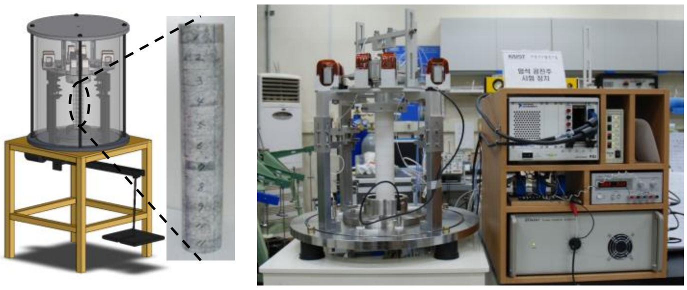
Rock Mass Dynamic Test apparatus (RMDT)

The RMDT apparatus is a modified Stokoe-type resonant column (RC) test device that has sufficient torque power to test rock column specimens for shear strains up to 10^{-2}%. Using this system, the characteristics of wave propagation in jointed rocks can be tested for small to intermediate shear strain levels.



Drive plate	Four-armed plate with magnets (Magnet: 70 mm × 50 mm × 25 mm)
Max. axial loading	2 MPa
Shear strain range	10^{-5}–10^{-2}%

Figure 16. Rock mass dynamic test apparatus.