GAIA

Geomechanics Alliance in Asia

# 1st GAIA workshop

## Atami, Japan

## 21st-24th February 2025

# Program

# GAIA

## Geomechanics Alliance in Asia

### Schedule

| 21st | | 22nd | | 23rd | | 24th | | 25th | |
|---|---|---|---|---|---|---|---|---|---|
| | | 7:00-8:00 | **Breakfast** | 7:00-8:00 | **Breakfast** | 7:00-8:00 | **Breakfast** | 7:00-8:00 | **Breakfast** |
| | | 8:50-9:00 | Opening | 9:00-9:50 | Morning I | 9:00-10:15 | Morning I | | |
| | | 9:00-10:15 | Morning I | 9:50-10:05 | **Break** | 10:15-10:35 | **Break** | | |
| | | 10:15-10:35 | **Break** | 10:05-10:55 | Morning II | 10:35-11:50 | Morning II | | |
| | | 10:35-11:50 | Morning II | 10:55-11:10 | **Break** | | | | |
| | | | | 11:10-12:00 | Morning III | | | | |
| | | 12:00-13:00 | **Lunch** | 12:00-13:00 | **Lunch** | 12:00-13:00 | **Lunch** & Closing | | |
| | | 13:30-14:45 | Afternoon I | 13:30-14:45 | Afternoon I | | | | |
| | | 14:45-15:05 | **Break** | 14:45-15:05 | **Break** | | | | |
| | | 15:05-16:20 | Afternoon II | 15:05-16:20 | Afternoon II | | | | |
| | | 16:20-16:40 | **Break** | 16:20-16:40 | **Break** | | | | |
| | | 16:40-17:40 | Poster Session | 16:40-17:40 | Discussion | | | | |
| | | 17:40-18:30 | **Break** | 17:40-18:30 | **Break** | | | | |
| 18:30-19:30 | **Dinner** | 18:30-19:30 | **Dinner** | 18:30-19:30 | **Dinner** | 18:30-19:30 | **Dinner** | | |
| 20:00-23:00 | **Ice breaker** | 20:00-21:00 | Keynote lecture I | 20:00-21:00 | Keynote lecture II | | | | |
| | | 21:00-23:00 | Social gathering | 21:00-23:00 | Social gathering | | | | |

# GAIA
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## Oral Session - February 22nd

| | | | |
|---|---|---|---|
| **Morning I** | Chair: G. Viggiani & P. Kanjanatanalert | | **Morphology** |
| 1 | 9:00-9:25 | Usman Ali | Crushing-induced size and shape evolution effect on critical states of soils |
| 2 | 9:25-9:50 | Yang Li | X-ray microtomography measurements and DEM assessments of coevolving particle size and shape |
| 3 | 9:50-10:15 | Yoshiki Miyasaka | Study of the effects of particle roughness on the mechanical behavior of 3D printed granular materials |
| **Morning II** | Chair: Y. Higo & A. Usman | | **Microstructure** |
| 4 | 10:35-11:00 | Ji-yuan Luan | Microscale Investigation of the Hydro-Mechanical Behaviour of Unsaturated Granular Soil by 4D Triaxial Compression on μ-CT |
| 5 | 11:00-11:25 | Pongsapak Kanjanatanalert | Micro- and Macroscopic behaviors of granular materials under a load-unload cycle |
| 6 | 11:25-11:50 | Zewei Zhang | Fabric characteristics of uncemented intact sand and its role in mechanical behavior |
| **Afternoon I** | Chair: Z. Yang & H. Jiang | | **Fluids in Soils** |
| 7 | 13:30-13:55 | Risa Komuro | Leaching behavior of naturally occurring heavy metals from soils: Interpretation with dual-diffusion model |
| 8 | 13:55-14:20 | Shaohan Wang | Investigation on Water Retention Characteristics of Granular Porous Media Using Micro-Computed Tomography and Lattice Boltzmann Modeling |
| 9 | 14:20-14:45 | Shizuka Eshiro | A theoretical model for water retention curves considering scanning curves based on X-ray micro-CT observations |
| **Afternoon II** | Chair: C. Couture & J. Kim | | **Further topics in Geotechnics** |
| 10 | 15:05-15:30 | Lalit Kandpal | Geotribological Insights into Non-Dilative Interface Shear Mechanisms |
| 11 | 15:30-15:55 | Sangjoon Park | Deep Operator Network for Surrogate Modeling of Poroelasticity with Random Permeability Fields |
| 12 | 15:55-16:20 | Xu Fang | Numerical study on shallow tunnel excavation in unsaturated ground: effective lateral pressure coefficient and scale effect |

# GAIA

## Geomechanics Alliance in Asia

### Oral Session - February 23rd

| | | | |
|---|---|---|---|
| **Morning I** | Chair: D. Takano & L. Kandpal | | **Fracturing** |
| 13 | 9:00-9:25 | Krishna | Experiments on the effect of gradation on macro-micromechanical granular response |
| 14 | 9:25-9:50 | Zirui Lu | Peridynamic modeling of hydraulic fracture in poroelastic media with leak-off |
| **Morning II** | Chair: J. Wang & Y. Yu | | **Cementation I** |
| 15 | 10:05-10:30 | Xiao Wei | Interactive Influence of water and fines contents on the strength of cement-stabilized sands |
| 16 | 10:30-10:55 | Abdelali Dadda | Microstructural Analysis of Biocemented Sands: Influence of Calcite Precipitation on Mechanical Behavior |
| **Morning III** | Chair: N. Lenoir & A. Dadda | | **Cementation II** |
| 17 | 11:10-11:35 | Ji-Peng Wang | Micro-Mechanics of Multiphase Geo-Materials based on Micro-CT Image Analysis: Unsaturated Soil, Vegetated Soil and Bio-Cementation |
| 18 | 11:35-12:00 | Lei Liang | Pore-scale perspectives of mechanical and hydrological behaviors of frozen salty sand |
| **Afternoon I** | Chair: S. Morguchi & S. Eshiro | | **Clay** |
| 19 | 13:30-13:55 | Jinwoo Kim | Addressing engineering-scale challenges in predicting the thermo-hydro-mechanical behavior of compacted bentonite: current research efforts at KAERI |
| 20 | 13:55-14:20 | Dominik Krengel | Implementing van der Waals forces for polytope particles in DEM simulations of clay |
| 21 | 14:20-14:45 | Yang Yu | A thermodynamics-based constitutive model for clays accounting for double porosity and fabric anisotropy |
| **Afternoon II** | Chair: J. Choo & D. Sugo | | **Liquefaction** |
| 22 | 15:05-15:30 | Gamaliel Jeevan Dewanto | Micromechanical Simulation of Soil Liquefaction Using Discrete and Finite Elements |
| 23 | 15:30-15:55 | Kwok-Kwan Lau | Development of a new liquefaction potential evaluation method using SPT and shear wave velocity data |
| 24 | 15:55-16:20 | Qizhuo Yang | Initial fabric conditions governing liquefaction resistance and post-liquefaction deformation of granular material |

# GAIA
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## Oral Session - February 24th

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|---|---|---|---|
| **Morning I** | Chair: J. Chen & D. Krengel | | **Earthquakes** |
| 25 | 9:00-9:25 | Cheng-Hsu Yang | Seismic Interaction Between Adjacent Buildings on Stratified, Liquefiable Ground |
| 26 | 9:25-9:50 | Diallo Abdourahmane | Density Analysis of Grain Behavior in a Box Excitation Model Using 3D DEM. |
| 27 | 9:50-10:15 | Sukanta Das | Seismic Behavior of Footings on Slopes: Insights from Experimental and Numerical Analysis |

| | | | |
|---|---|---|---|
| **Morning II** | Chair: M. Kikumoto & S. Das | | **Landslides** |
| 28 | 10:35-11:00 | Daichi Sugo | Large-area Slope Stability Analysis using Three-dimensional Limit Equilibrium Method with Ellipsoidal Slip Surfaces and Particle Swarm Optimization |
| 29 | 11:00-11:25 | Jian Chen | Influence of Grain Size and Mass Dynamics on Landslide Simulations Using DEM |
| 30 | 11:25-11:50 | Nilo Lemuel J. Dolojan | Wide-area debris flow hazard evaluation using depth-integrated Lagrangian models |

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## Poster Session - February 22nd

**P01. Akihiko Kondo**

Visualization of load transmission using mechano-luminescent-coated particles and its application for dynamic problems

**P02. Ayana Tamura**

Governing equations for Suffusion processes based on mixture theory

**P03. Florez Farfan Jhon Jairo**

Implementation of Mini-CPT device for evaluation of repeated liquefaction after a long duration earthquake using centrifuge modelling

**P04. Israt Jahan**

Predictive Modeling of Clay Behavior under TMC Stresses Using Advanced DEM for Nuclear Waste Containment

**P05. Jinyong Kim**

Coupled MPM and Level-Set Simulation of Indentation Tests on Granular Materials

**P06. Juhyeon Kim**

An investigation of the Role of the Constitutive Model in the Simulation of FEBEX Mock-up Test

**P07. Qi Zhang**

Response of suction bucket foundation subjected to wind and earthquake loads on liquefiable sandy seabed

**P08. Yuki Matsuoka**

A Constitutive Model for Rock Joints Considering Time and Rate Dependency of Friction Based on Critical State Theory

**P09. Yusuke Takayama**

Temperature effect on bentonite deformation behavior

**P10. Makoto Okuda**

Rotary crushing and mixing (Twister) Method

# Keynote lectures

# Six memos for the next generation of researchers in geomechanics

Gioachino Viggiani[1*]
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“Six Memos for the Next Millennium” is a book based on a series of lectures written by the Italian writer Italo Calvino for the Charles Eliot Norton Lectures at Harvard. The lectures were to be given in English in the fall of 1985, but Calvino died before delivering them. The "memos" are lectures on six literary qualities whose virtues Calvino wished to recommend to the then-approaching millennium: lightness, quickness, exactitude, visibility, multiplicity, and consistency. Inspired by Calvino, I have prepared a thirty-minute talk on six items that I wish to recommend to the next generation of researchers in geomechanics: fundamentals concepts, memory of the past, the value of uselessness, do not mistake tools for ideas, going deep(er), and openness.

# Developing constitutive models for granular materials using stress probing tests

Zhongxuan Yang[1*]
[1]Zhejiang University
[*]Corresponding author: zxyang@zju.edu.cn

Nonlinearity, irreversibility, and state-dependency are key features of the mechanical behavior of soils. To develop a rigorous constitutive model for soil, a deep understanding of its incremental stress-strain response is crucial. This talk introduces a numerical stress probing technique based on the discrete element method (DEM) to explore the strain response of soil subjected to stress increments in different directions. The influence of density and stress state on the incremental behavior is systematically analysed. A novel approach is proposed to derive essential components of the constitutive model from the response envelopes, including the yield surface, plastic flow direction, hardening rule, and plastic modulus. The model's predictive capability is demonstrated by simulating soil behavior in both DEM simulations and laboratory experiments under varying loading conditions. Additionally, this method can be extended to develop models that account for other soil behaviours, such as fabric anisotropy, pressure sensitivity, cyclic hysteresis, and history-dependent loading.

# Abstracts

*Morphology* 01

# Crushing-induced size and shape evolution effect on critical states of soils

Usman Ali[1*]
[1]Yokohama National University, Yokohama, Japan
[*]Corresponding author: ali-usman-fc@ynu.ac.jp

Soil particles subjected to high stress or strain can undergo crushing, leading to changes in gradation and particle shape. Previous studies have confirmed that gradation broadening shifts the critical state line (CSL) downward in the compression plane, with minimal impact on critical state shear strength. This study examines the impact of crushing-induced co-evolution of particle size and shape on soil critical states using a calibrated and validated discrete element model of a biaxial shear test. Samples with varying levels of crushing were generated to replicate real crushing phenomena, and their shearing behavior was studied. The findings confirmed a downward shift of the CSL in the compression plane, with the magnitude of this shift being influenced by both size and shape distributions. However, critical state shear strength was found to depend primarily on particle shape distribution only. Moreover, detailed particle-scale responses were investigated, providing deeper insights into the observed behavior.

*Morphology* 02

# X-ray microtomography measurements and DEM assessments of coevolving particle size and shape

Yang Li[1*]
[1]Port and Airport Research Institute
[*]Corresponding author: lyutokyo16@gmail.com

This oral presentation presents how particle size and shape simultaneously evolve during grain crushing using synchronized X-ray microtomography measurements (SMT) and discrete element modelling (DEM). The observations from SMT and DEM indicate that continuous breakage causes both particle size and shape to converge towards their ultimate statistical distributions. Particles with considerably different initial shapes are observed to approach a common attractor regardless of their initial morphology. Using a newly proposed shape evolution index, it is shown that the particle shape evolves relatively faster than its size, implying that the shape tends to reach its attractor point faster than the grading reaches its ultimate size distribution. With supplementary microscopic results in DEM, it is found that their interparticle force distributions show a convergent form during breakage. The main findings pave the way for refining breakage mechanics theories to incorporate particle shape, offering insights into the self-organizing characteristics of fragmented granular systems.

*Morphology* 03

# Study of the effects of particle roughness on the mechanical behavior of 3D printed granular materials

Yoshiki Miyasaka[1*]
[1]Kumamoto University
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The macroscopic properties of granular materials like sands depend on the geometrical properties of particles at the microscale such as particle shape and surface roughness. However, it's difficult to separate and evaluate specific properties in natural heterogeneous granular material. The objective of this study is the experimental investigation of the effects of surface roughness on the mechanical properties of granular materials and the kinematics of particles. Two types of 3D printed ellipsoidal particles with different roughness, the smooth and the rough, are fabricated and the triaxial experiments are conducted within an X-ray tomography. The peak stress of the rough particle specimen is twice as much compared to the smooth particle specimen. The kinematics of the particles like displacements, particle orientation and the contacts between particles are analysed using X-ray tomography images, and the effects of particle roughness on the mechanical behavior is discussed from the view of their particle scale.

*Microstructure* 04

# Microscale Investigation of the Hydro-Mechanical Behaviour of Unsaturated Granular Soil by 4D Triaxial Compression on μ-CT

Ji-yuan Luan[1*]
[1]Shandong University
[*]Corresponding author: jasperluan@outlook.com

The hydro-mechanical performance of unsaturated granular soils is decisively influenced by the macroscopic physical properties, and the micro-structure also keeps a vital role in the global strength. This work presents a study about developing and validating a mini-triaxial test apparatus suiting for μ-CT system. The suction-controlled in-situ triaxial compression CT scanning tests are performed for this 4D (3-Dimensional+Dynamic) research, obtaining micron-level resolution CT images at several different loading states. The micro-mechanisms of unsaturated granular soils upon triaxial shearing are investigated based on the segmentation CT images, analysing for three-phase spatial distribution, interfacial effect and different type inter-particle contact evolution. As shearing expansion, large-volume pore-water clusters are decomposed into discontinuous small-volume liquid clusters in pore space (partially behaved as liquid bridges). The wetted inter-particle contacts of the unsaturated granular sample have a relatively high proportion, and the spatial distribution of wetted inter-particle contact orientations is relatively uniform, the solid skeleton of unsaturated sample has higher strength.

*Microstructure* 05

# Micro- and Macroscopic behaviors of granular materials under a load-unload cycle

Pongsapak Kanjanatanalert[1*]
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Granular materials exhibit complex behavior under load-unload cycles. From a macroscopic point of view, a noticeable reduction in stiffness can be observed during the first few cycles. This reduction highlights the potential for overestimating the strength of granular materials at the initial stage if cyclic loading effects are ignored. However, the mechanism underlying this stiffness reduction remains unclear. Since the transmission of forces occurs through particle contacts, forming a network, it is crucial to investigate behaviours at both particle and inter-particle scales. In this study, we conducted mean-stress-constant biaxial shearing with a load-unload cycle using aluminium rods marked with special stickers to capture particle movement and rotation. The collected data are analysed to establish correlations between particle-scale information and macroscopic responses. By connecting these scales, this research aims to enhance understanding of the complex behavior of granular materials under load-unload cycles.

*Microstructure* 06

# Fabric characteristics of uncemented intact sand and its role in mechanical behavior

Zewei Zhang[1*]
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Uncemented intact sand has been reported to exhibit significantly different properties from reconstituted sand due to their distinct inherent fabric. In this study, X-ray micro-computed tomography (XRCT) scans are performed on both frozen intact and reconstituted sand specimens to obtain their fabric characteristics. Results show that the particle orientation of intact sand exhibits an obvious concentration within an inclined sedimentary plane, while reconstituted sand tends to orient evenly in the horizontal plane. Intact sand has a greater coordination number and larger contact area than reconstituted sand, particularly for coarse particles. An interlocking variable I, characterizing the contact area, is proposed to link microstructure observations with macro-mechanical properties. The variable is introduced to the Critical State Theory (CST) via the state parameter and formulations for dilatancy and plastic modulus are proposed and validated based on this theory. It provides a framework to unify the constitutive modelling of uncemented structured intact sand and reconstituted sand.

*Fluids in Soils* 07

# Leaching behavior of naturally occurring heavy metals from soils: Interpretation with dual-diffusion model

Risa Komuro[1*]
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In Japan, excavation work sometimes encounters soils contaminated with naturally occurring heavy metals such as lead and arsenic. Since they are formed by thermal metamorphism and sedimentation on the seafloor, they are contaminated throughout the interior of the particles and are expected to exhibit different leaching behavior from artificially contaminated soils. We developed a novel numerical model, the "dual-diffusion model", to describe the leaching behavior of heavy metals encapsulated within soil particles. This mechanism-based model accounts for contaminants transport in two pore spaces: advection, dispersion, and diffusion in inter-particle pore water, and diffusion and adsorption/desorption in intra-particle pore water. The model analysis revealed that soils composed of larger particles pose significantly delayed leaching, both in closed systems and under permeable conditions. The proposed model is expected to accurately assess the leaching risk from ground containing rocks with diameters ranging from several tens to a hundred millimetres.

*Fluids in Soils* 08

# Investigation on Water Retention Characteristics of Granular Porous Media Using Micro-Computed Tomography and Lattice Boltzmann Modeling

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The key to correctly understanding the hydraulic-mechanical properties of unsaturated soils lies in grasping the correlation between the microstructure of soil and the macroscopic water retention characteristics. The three-phase topological morphology at key suction states was obtained through in-situ desaturation tests on granular media, providing insights into the cluster statistics and local grain environments of real porous media. Subsequently, the three-dimensional (3D) simulation domain was constructed by a subvolume from X-ray computed tomography (CT) images. The topological interfacial distribution during the desaturation process of unsaturated granular media was reproduced through the single-component multiphase Shan-Chen Lattice Boltzmann modelling (SC-LBM). The topological distribution, number of liquid and gas clusters, contact modes between grains and liquid, and cohesive strength were numerically explored. The effective stress parameter was theoretically solved utilizing porosity, degree of saturation, interfacial area, and matric suction. The LBM numerical results show good match with the experimental results.

*Fluids in Soils* 09

# A theoretical model for water retention curves considering scanning curves based on X-ray micro-CT observations

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This study developed a theoretical water retention curve model based on X-ray computed tomography observations during the water retention test. Drainage and imbibition clusters were extracted from image differences between two images capturing different saturation states. Image analyses of the shape of these clusters and their distances to soil particles revealed that during drying, water drained in simple shape from pore centres, while during wetting, water imbibed in complex shape near particle surfaces before filling pores. A theoretical water retention curve model with scanning curves was proposed using spherical soil particles in rhombohedral unit cells, considering density and particle size distribution. Drainage and imbibition behaviours in each unit cell were modelled differently: the hemisphere model for drainage and the inscribed sphere model for imbibition, reflecting observed behaviours in image analyses. This approach qualitatively represented scanning curves, overcoming the limitations of previous models that used the same model for both behaviours.

*Further topics* 10

# Geotribological Insights into Non-Dilative Interface Shear Mechanisms

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The interface shear mechanism of geomembrane and sand is critical in geosystem design due to its role as a potential plane of weakness, governed by complex interactions that deviate from traditional friction laws. This study aims to understand the shear behavior of non-dilative interfaces by linking particle kinematics and tribological aspects in a geotribological framework. Interface direct shear tests coupled with X-ray tomography were performed on subangular sand (SA_S) and smooth glass beads (S_GB) of similar size (2–4.75 mm) but differing morphologies with HDPE geomembrane under three normal stresses (50, 100, and 200 kPa). Strain fields, particle kinematics, and surface roughness were analysed. Results revealed higher shear stress and plowing for SA_S due to its rougher morphology compared to S_GB. Increased normal stress reduced particle kinematics, enhancing plowing. This study highlights the influence of particle shape and normal stress on interface shear mechanisms, providing insights for realistic force prediction models.

*Further topics* 11

# Deep Operator Network for Surrogate Modeling of Poroelasticity with Random Permeability Fields

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Poroelastic modelling is widely used to address problems with random permeability fields, accounting for spatial heterogeneity and uncertainty in permeability. In such cases, surrogate modelling is often employed to enable efficient random field simulations without significantly compromising accuracy. However, existing surrogate modelling approaches for poroelasticity leave room for improvement. In this work, we present a deep operator network (DeepONet)—a neural operator framework that maps functions to functions—as a novel surrogate modelling approach for poroelastic problems with random permeability fields. The DeepONet model takes permeability fields as input functions and outputs the primary variables of poroelasticity. To ensure generality and computational efficiency, we preprocess the dataset using nondimensionalization and Karhunen–Loève expansion.We evaluate the performance of the DeepONet surrogate model through two numerical examples in poroelasticity: soil consolidation and ground subsidence induced by groundwater extraction. The results demonstrate that the DeepONet surrogate model achieves poroelastic simulations orders of magnitude faster than finite element methods while maintaining reasonable accuracy.

*Further topics* 12

# Numerical study on shallow tunnel excavation in unsaturated ground: effective lateral pressure coefficient and scale effect

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The finite element method was used to investigate the shallow tunnel excavation in unsaturated ground. Initially, an unsaturated soil model was implemented in PLAXIS 2D to reproduce the trapdoor tests under various trapdoor widths, overburden heights, and groundwater levels. The consistency of the ground reaction curve, the total and effective loosening pressures (ultimate pressure on the trapdoor), and the shear bands formation were observed, confirming the reliability and accuracy of the numerical methodology. The numerical simulations revealed that the effective lateral pressure coefficient of K, varied within a range of 1.0 to 1.4, irrespective of the groundwater level, the trapdoor width, or the overburden height. Additionally, numerical simulations revealed that the total loosening pressure normalized by initial pressure in saturated ground varied with the trapdoor width under different groundwater levels, indicating the presence of the scale effect in unsaturated ground. Therefore, the unsaturated condition must be considered during tunnel excavation.

*Fracturing* 13

# Experiments on the effect of gradation on macro-micromechanical granular response

Krishna[1*]
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When granular materials such as railway ballast are subjected to external load it undergoes particle level interaction depending on particle characteristics such as particle size, gradation, shape, and surface roughness. During service life, railway ballast undergoes fragmentation due to various geotechnical phenomenon such as weathering, erosion, cyclic loading etc. thus requiring recouping of ballast for maintenance purposes. This process leads to change in ballast gradation potentially affecting shear response, bearing capacity, cushioning effect, permeability, compatibility, drainage etc. In this study, samples composed of Schneebeli rods made of aluminium were prepared in the laboratory with different initial gradations representing ballast condition at different stages during service life. Biaxial shearing test are conducted, and the effect of gradation change on macro-micromechanical responses is studied.

*Fracturing* 14

# Peridynamic modeling of hydraulic fracture in poroelastic media with leak-off

Zirui Lu[1*]

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Hydraulic fracturing is widely employed in engineering practice such as shale gas exploration and enhanced geothermal systems, where the porous solid is fractured by fluid injection. A key factor controlling fracking efficiency is the leak-off, which refers to the loss of fracturing fluid into the surrounding porous solid. This work introduces a novel peridynamics-based computational approach for modelling hydraulic fracturing in porous media. The model integrates a semi-Lagrangian peridynamics (PD) formulation for simulating free-flowing fluids and a poroelastic PD formulation to capture the deformation and fracturing of porous solids with seepage. The fluid-solid interaction (FSI) is modelled by coupling the two PD formulations, accounting for hydraulic forces on fracture surfaces and fluid leak-off into the porous medium.

*Cementation* 15

# Interactive Influence of water and fines contents on the strength of cement-stabilized sands

Wei Xiao[1*]
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Compacted cement-stabilized soils are important geomaterials for construction projects involving backfilling, embankment construction, and ground improvement. The unconfined compressive strength, as one of the key design parameters, is affected by a variety of influencing factors in a complicated way. This study aims to obtain practical insights into the effects of water and fines content on the UCS of cement-stabilized sands, which is commonly encountered in reclamation projects.

*Cementation* 16

# Microstructural Analysis of Biocemented Sands: Influence of Calcite Precipitation on Mechanical Behavior

Abdelali Dadda[1*]
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The mechanical behavior of biocemented soils is primarily influenced by their microstructural characteristics, including the calcite volume fraction and its distribution within the pore network. In this study, various microstructural properties—such as contact surface area, contact type, and specific surface area—are calculated from 3D images of biocemented sand samples obtained through X-ray tomography. The evolution of these properties with respect to calcite volume fraction is examined. Regardless of the calcite content, the precipitation of calcite is found to be concentrated at the contact points between grains. These findings are validated by comparing the imaging results with analytical predictions, assuming the granular medium consists of a periodic simple cubic arrangement of grains and considering two extreme precipitation scenarios: one localized at the grain contacts, and the other forming a uniform coating on the sand grains.

*Cementation* 17

# Micro-Mechanics of Multiphase Geo-Materials based on Micro-CT Image Analysis: Unsaturated Soil, Vegetated Soil and Bio-Cementation

Ji-peng Wang[1*]
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Under the influence of climate change, the frequent occurrence of extreme weather has led to increasingly prominent engineering geological disasters. Vegetation slope protection technology and Microbial Induced Calcite Precipitation (MICP) reinforcement technology have gained attention for their green and low-carbon advantages. However, the unclear micro-mechanism of multiphase geotechnical materials limits the development of macro theories and engineering applications. This study, based on high-resolution CT scanning technology and related image analysis methods, investigates the micro-mechanical properties of multiphase geotechnical materials, including unsaturated soil, root-soil complexes, and bio-cemented sand, providing scientific evidence for validating macro theories and guiding practical engineering applications.

*Cementation* 18

# Pore-scale perspectives of mechanical and hydrological behaviors of frozen salty sand

Lei Liang[1*]
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Climate change can degrade permafrost and therefore trigger geological disasters and release materials trapped in permafrost. Mechanical behavior and material transport capacity of permafrost are crucial, but there are few studies from a microscopic perspective. Salt is widely distributed in nature. The presence of salt enables ice to coexist with unfrozen brine at sub-zero temperatures, which affects the mechanical and seepage properties of permafrost. In-situ CT triaxial tests are conducted on frozen sands. The morphology and distribution of porous ice are statistically analysed to assess the cementation effect via ice-sand contact area and cementation strength. The creep behavior of ice is explained from the perspective of thermodynamics. To address the transport capacity of frozen sand, we evaluate the connectivity and permeability of unfrozen water. Permeability in saline frozen sands can be orders of magnitude higher than values typically reported, revealing the potential for rapid mass transport through connected unfrozen water.

*Clay* 19

# Addressing engineering-scale challenges in predicting the thermo-hydro-mechanical behavior of compacted bentonite: current research efforts at KAERI

Jinwoo Kim[1*], Minseop Kim[1], Jin-Seop Kim[1]
[1]Disposal Performance Demonstration Research Division, Korea Atomic Energy Research Institute (KAERI)
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Compacted bentonite is a crucial component of engineered barrier systems (EBS) for high-level radioactive waste (HLW) disposal. Predicting its long-term performance under operating scenarios is critical yet challenging due to the complex thermo-hydro-mechanical (THM) coupling involving high temperatures and high suction. While such THM behavior of compacted clays has been widely studied over the past decades, a key challenge lies in upscaling laboratory insights to engineering-scale applications. This talk presents current research efforts at KAERI on Bentonil-WRK to address uncertainties under field conditions, including the variation of water retention curves due to mineralogical composition, the role of gap spaces in water infiltration under thermal gradients, and the localized deformation in bentonite blocks and backfill. Experimental observations are presented and discussed to offer insights for optimizing bentonite quality based on montmorillonite content, designing gap spaces and fillers, and developing and validating constitutive models to accurately predict the observed behaviours.

*Clay* 20

# Implementing van der Waals forces for polytope particles in DEM simulations of clay

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Clay minerals are non-spherical nano-scale particles that usually form flocculated, house-of-card like structures under the influence of inter-molecular forces. This preferred spatial arrangement means that their aggregates are highly compressible under load and thus highly relevant for geotechnical studies. Numerical modelling of clays is still in its infancy as the required inter-particle forces are available only for spherical particles. As a result, current DEM simulations either do not reproduce the true shape of clay minerals or are an inefficient, coarse numerical integration. A polytope approach would allow shape-accurate forces and torques while simultaneously being more performant.

The Anandarajah solution provides an analytical formulation for Van der Waals forces for cuboid particles but is in its presented form not suited for implementation in DEM simulations. Force and force point diverge for parallel or perpendicular particle orientation and do not consider finite particle size, while in general, the solution is restricted to quasi-2D configurations.

In this work we discuss the necessary changes for a functional implementation of the Anandarajah solution in a DEM simulation of rectangular particles and their extension to cuboid particles. In particular, we show that the orientational discontinuity can be dealt with by means of a piece-wise solution of the forces, while the

influence finite particle size on the force and force point can approximated with a geometric Ansatz to ensure a smooth variation with change in relative position and orientation. The resulting van-der-Waals force model then not only reproduces the van-der-Waals forces determined by numerical integration but also leads to the expected flocculated spatial arrangement of the clay minerals. We further discuss the changes necessary to extend our implementation from two dimensions to three dimensions.

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# A thermodynamics-based constitutive model for clays accounting for double porosity and fabric anisotropy

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Clays are natural materials characterised by a complex internal microstructure consisting of particles often arranged to form aggregates. Recent advances in experimental techniques, such as Mercury Intrusion Porosimetry (MIP) combined with digital image correlation analysis from Scanning Electron Microscopy (SEM), make it possible to identify at least two different-scaled porosities, the intra-aggregate and inter-aggregate pores, and to track their evolution upon loading. Furthermore, iso-oriented aggregates often result in an anisotropic macro-mechanical response. In continuum mechanics, constitutive modelling of clays can benefit from the aforementioned experimental evidence to identify measurable micro-inspired internal variables to back-predict the observed macroscopic response. In this study we proposed a thermodynamics-based constitutive model for clays, with two selected scalar void ratios and a second order fabric tensor. The formulation takes advantage of a new strategy of initialisation of the two porosities based on the results of micro-experimental results to reproduce the whole mechanical response of clays, from the early irreversible response to failure.

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# Micromechanical Simulation of Soil Liquefaction Using Discrete and Finite Elements

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Liquefaction of soil is very often discussed in a very hand waving manner: the movement of fluid relative to particles is graphically visualized, but the motion is not based on any computation via actual equations of motion. In this research we present two-dimensional micromechanical computations of vibrated grain matrices in fluid where the granular particles are modelled with a discrete element method for elastic polygons and the fluid is incorporated around the particles via a finite element method for incompressible fluids. Under external vibration, we show how the granular matrix is liquefied and can escape through gaps on the surface of the system, as is the case in many liquefaction events during earthquakes. We will discuss the liquefaction based on the evolution of the force network in the granular matrix.

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# Development of a new liquefaction potential evaluation method using SPT and shear wave velocity data

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Recognizing limits in conventional simplified approaches for assessing liquefaction resistance or cyclic resistance ratio CRR, this work concentrated on the influences of soil density and fabric to CRR and investigated the suitability of a novel approach which combines Standard Penetration Test (SPT) and shear wave velocity Vs data. It is aware that density and SPT blow counts N-value are closely related, while small-strain characteristics such as Vs or small-strain shear modulus G0 are better indicators of soil fabric. A new CRR evaluation method considering both SPT and Vs data was established, referencing to a recently developed empirical correlation of Vs-CRR in which the relative density is normalized. The applicability and prediction performance of the proposed approach were examined using a global dataset of liquefaction case histories. The new evaluation method has been shown to improve overall accuracy and prevent false-positive predictions.

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# Initial fabric conditions governing liquefaction resistance and post-liquefaction deformation of granular material

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This study employs three-dimensional discrete element method (DEM) numerical simulations to investigate the influence of initial fabric on liquefaction resistance and post-liquefaction deformation. The microscopic metrics of interest include particle orientation fabric anisotropy, contact normal fabric anisotropy, coordination number, void ratio, and redundancy index. It is found that the initial coordination number and redundancy index are pivotal in influencing liquefaction resistance. In terms of post-liquefaction shear deformation, conventional fabrics are found not to be the governing factor for liquefaction induced shear strain. Instead, the mean neighbouring particle distance (MNPD), a fabric measure introduced by Wang et al. (2016) for two-dimensional applications, is identified as the sole determinant of post-liquefaction shear strain. Furthermore, a unique correlation between the initial MNPD and the ultimate saturated post-liquefaction shear strain is revealed, highlighting the potential of MNPD as a critical fabric for predicting the post-liquefaction behavior of sand.

*Earthquakes* 25

# Seismic Interaction Between Adjacent Buildings on Stratified, Liquefiable Ground

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Earthquake-induced soil liquefaction typically results in post-earthquake foundation settlement and tilt, which can cause significant structural damage (e.g., during the 1995 Kobe earthquake, the 1999 Chi-Chi earthquake, and the 2016 Meinong earthquake). This issue is particularly critical in urban environments where buildings are often constructed in close proximity to each other. This study investigates the structure-soil-structure interaction (SSSI) between adjacent three-story buildings on layered, liquefiable soils using three-dimensional finite element analysis. The research examines the effects of building spacing, soil layer configurations, and earthquake intensity through numerical sensitivity analyses, considering four soil profiles and three seismic intensity levels. Results demonstrate that buildings with shorter spacing experienced significantly greater foundation settlements and permanent tilt. In general, increasing building spacing led to small foundation tilts for soil profiles without interlayers. Additionally, in models with multiple layers of sand and silt, the spacing of buildings had a limited effect on the tilting of permanent foundations. On the other hand, for closely spaced structures, both settlement and tilt increased with earthquake intensity. However, increasing earthquake shaking intensity had a minor impact on foundation tilts for structures at larger spacing, indicating minimal SSSI effects. These findings emphasize the critical importance of considering building spacing, stratigraphic variability, and shaking intensity in seismic design for structures on liquefiable soils.

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# Density Analysis of Grain Behavior in a Box Excitation Model Using 3D DEM.

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This study investigates the dynamic behavior of irregularly shaped granular materials subjected to one-dimensional wall vibration using 3D clumped-sphere discrete element method (DEM). Initial dense and loose granular assembly were subjected to sinusoidal horizontal vibrations within a box container with various amplitudes and frequencies. The study aims to identify the most effective vibration parameters that optimize the densification rate from an initially dense to a looser model. Bulk density analysis revealed that initially, looser models experienced a more substantial increase in density over time compared to denser models after 5 seconds of excitation. After analysis of loose and dense subregions of the initially looser model, it was found that the dense region bulk density rate was more sensitive to changes in amplitude and frequency. These findings provide insights into the optimal adjustment of vibration parameters to improve compaction efficiency in tamping operations, contributing to maintenance and track stability. Additional simulations will clarify the observed trends and support best practices for achieving maximum ballast layer compaction through controlled excitation.

*Earthquakes* 27

# Seismic Behavior of Footings on Slopes: Insights from Experimental and Numerical Analysis

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The seismic behavior of footings located on slopes is a critical area of study in geotechnical engineering, given the complex interaction between footing and slope during seismic events. This study investigates the dynamic response of footings placed near slopes under various ground motion scenarios using both experimental and numerical approaches. Key parameters such as the slope angle, footing distance from the crest, and soil properties were analysed to evaluate their influence on bearing capacity and settlement characteristics. Results highlight the amplification of ground motion near the slope crest and its impact on the stability and deformation of the footing. The study also identifies the critical zones where the footing performance significantly deteriorates during seismic loading. Findings provide essential insights for designing foundations in hilly terrains, ensuring safety and stability under earthquake conditions, and contribute to the development of seismic design guidelines for footing on slopes.

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# Large-area Slope Stability Analysis using Three-dimensional Limit Equilibrium Method with Ellipsoidal Slip Surfaces and Particle Swarm Optimization

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The risk of Landslides has been increasing due to climate change, emphasizing the need for large-area slope hazard assessments. Scoops 3D, an open-source software developed by U.S. Geological Survey, is widely used for large-area slope stability analysis using three-dimensional Limit Equilibrium Method (LEM). This software assumes a spherical slip surface, which provides a significant advantage in computational efficiency. However, in complex terrains such as mountainous slopes, this assumption limits the ability to represent the geometry of slip surfaces accurately. In this study, we introduce an ellipsoidal slip surface to enhance the accuracy of large-area slope stability analysis using LEM. We also propose a method to suppress the increased computational cost associated with the ellipsoidal slip surface assumption. Furthermore, Particle Swarm Optimization (PSO) is employed to optimize the search for critical slip surfaces, and effectiveness of the optimization in reducing computational costs in large-area LEM analysis is discussed.

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# The Influence of Grain Size and Mass Dynamics on Landslide Simulations Using DEM Influence of Grain Size and Mass Dynamics on Landslide Simulations Using DEM

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Understanding the dynamics of landslides is critical for improving mitigation strategies. We used an advanced discrete element method (DEM) framework to model landslides, overcoming traditional limitations by incorporating mass entrainment. In this study, we performed detailed three-dimensional simulations on realistic slope models based on high-resolution geomorphic data from the Aso Bridge landslide triggered by the 2016 Kumamoto earthquake. Models with different grain sizes were constructed to investigate the effects of grain size and mass entrainment on landslide behavior. The results show that smaller grains significantly increase the spreads and runout distances. Particle-level statistical analysis supports this, showing greater maximum travel distances and a higher percentage of particles traveling further in models with smaller grains. Importantly, this increase includes both the initially released and entrained mass during the landslide, underscoring the critical importance of considering mass entrainment in landslide dynamics and mitigation design.

*Landslides* 30

# Wide-area debris flow hazard evaluation using depth-integrated Lagrangian models

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This study presents a computationally efficient approach for modelling debris flows over wide areas using the mesh-free Lagrangian smoothed particle hydrodynamics (SPH) method. The debris flow is idealized as a single-phase homogeneous viscous fluid, whose behavior is governed by the depth-integrated shallow water equations. Discretizing the fluid body into particles in a Lagrangian framework, the governing equations are solved with little to no interaction with the background mesh. This approach significantly reduces computational costs, particularly for scenarios with extensive computational domains but localized failure areas. Large-scale experiments and actual debris flow disasters are then simulated to assess the model's applicability. The results demonstrate that the method provides a computationally efficient and reliable model for evaluating, assessing, and mitigating debris flow hazards over wide areas.

*Poster* 01

# Visualization of load transmission using mechanoluminescent-coated particles and its application for dynamic problem

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Glass beads were coated with a mixture of mechanoluminescent (ML) paint and epoxy resin in order to visualize particle-level force distribution through an analogous granular material. Load tests were conducted on single columns of coated glass particles to calibrate luminance to diametrical forces transmitted through the particles and particle contacts. Coated glass particles were placed in a transparent plane strain container and subjected to biaxial loading to visualize the load transmission through an analogous granular material placed in a regular packing. The anisotropy of chains of load transmission during loading was detectable. The sum of contact forces deduced from particle luminance are shown to be in agreement with applied boundary loads.

As an application of these coated glass particles, a shaking table test was conducted using model soil and a plate with a mass at the tip to visualize the transition of the force chain during the vibration.

*Poster* 02

# Governing equations for Suffusion processes based on mixture theory

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In this study, the phenomenon called “suffusion”, in which fine-grained soil is discharged by seepage flow, is formulated in the framework of a soil/water two-phase mixture. The saturated soil is considered as a continuum model consisting of four components in two phases: solid phase (solid skeleton and erodible fine particles) and fluid phase (fluidized particles and pure fluid), and suffusion is expressed as a phase transition from erodible fine particles in the solid phase to fluidized particles in the fluid phase. The governing equations are formulated by paying attention to the mass exchange and momentum exchange between the phases. The results of seepage flow analysis using the finite element method confirm that the permeability of the soil changes with time due to the effect of suffusion.

*Poster* 03

# Implementation of Mini-CPT device for evaluation of repeated liquefaction after a long duration earthquake using centrifuge modeling

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This study investigates the hazard of repeated liquefaction in sand specimens composed of Toyoura silica sand, prepared using the air pluviation method with a relative density of 67%. A series of three Cone Penetration Tests (CPTs) were conducted, followed by two shaking events with similar characteristics. The evolution of excess pore water pressure was monitored using pore water pressure transducers, while accelerometers captured the dynamic response of the soil. Results revealed that the first shaking event induced widespread liquefaction across the specimen, accompanied by a significant increase in tip resistance. In contrast, the second shaking event demonstrated a reduced susceptibility to liquefaction, likely due to densification and strain hardening effects caused by the initial event. This study highlights the implications of cyclic loading on soil behavior, with potential applications in earthquake engineering and geotechnical hazard assessment.

*Poster* 04

# Predictive Modelling of Clay Behavior under TMC Stresses Using Advanced DEM for Nuclear Waste Containment

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This research explores the development of a predictive model for clay behavior under thermal, mechanical, and chemical (TMC) stresses using advanced Discrete Element Method (DEM) simulations. Since bentonite clay's low hydraulic conductivity and swelling capacity are critical for long-term safety in hazardous waste repositories, the study, which focuses on nuclear waste containment, highlights the stability and efficacy of this material. To capture essential swelling, temperature interactions, and structural resilience over time, the model looks at how individual bentonite particles react to TMC circumstances. Experimental comparisons, specifically with results from CRIEPI, validate the DEM findings and provide insight into clay swelling and self-healing behavior in a range of heat and stress conditions.

*Poster* 05

# Coupled MPM and Level-Set Simulation of Indentation Tests on Granular Materials

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The indentation of rigid objects into granular materials is a common phenomenon in geotechnical engineering. However, numerical simulation of such indentation remains challenging, particularly for indenters with complex geometries. This study evaluates the capabilities of a coupled Material Point Method (MPM) and level-set method for simulating the indentation of rigid objects into granular materials. The MPM simulates the granular material, while the level-set method represents indenters with arbitrary geometries. For validation, indentation tests are conducted on a sand-bentonite mixture using three types of indenter geometries: a hexagram, a Berkovich tip, and a mask. The constitutive behavior of the sand-bentonite mixture is modelled using a Drucker-Prager Cap plasticity model with parameters calibrated to triaxial test data. Comparisons of the simulation results with experimental data demonstrate that the coupled MPM and level-set method can reasonably capture the force-displacement responses for the tested indenter geometries. Additionally, a sensitivity analysis identifies key parameters influencing the mechanics of indentation in granular materials.

*Poster* 05

# An investigation of the Role of the Constitutive Model in the Simulation of FEBEX Mock-up Test

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The mechanical behavior of compacted bentonite in high-level radioactive waste disposal systems is often modelled using advanced constitutive models, such as the Barcelona Basic Model (BBM). While these models provide detailed representations, they require extensive parameter calibration and computational costs in simulations. However, the extent to which bentonite's detailed constitutive behavior affects the overall system performance remains uncertain. To address this, we performed coupled thermo-hydraulic-mechanical (THM) simulations of the FEBEX Mock-up Test—a benchmark study in radioactive waste disposal—using identical thermal and hydraulic parameters but two different constitutive models: linear elasticity and BBM. Both models accurately predicted temperature variations, indicating that the constitutive behavior of bentonite has minimal impact on the thermal performance. However, the linear elastic model underestimated relative humidity by over 15% and failed to reproduce total stress changes accurately. These results underscore the need to select constitutive models based on the specific performance metrics of interest in the disposal systems.

*Poster* 06

# Response of suction bucket foundation subjected to wind and earthquake loads on liquefiable sandy seabed

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Offshore wind turbines (OWTs) are now being built in seismically active regions with the implementation of net-zero emissions of carbon dioxide. Safe operation of OWTs on suction bucket foundation is severely threatened by earthquake-induced liquefaction. This research investigated the performance of the suction bucket foundation supported the OWT in the liquefiable sand under wind and earthquake loads. Various factors affecting seismic responses of the suction bucket foundation were analysed, including the wind loads, seismic loads, aspect ratios of suction buckets, and sand densities. The responses were evaluated in terms of accelerations, excess pore water pressure ratios, horizontal displacements, settlements, and rotations of the OWT under wind and earthquake loads. The OWT may suffer a permanent tilt to exceed the serviceability limit state of the OWT due to wind loads, earthquakes, and liquefaction. The deformation mechanism of the suction bucket foundation under wind loads and earthquakes was revealed.

*Poster* 08

# A Constitutive Model for Rock Joints Considering Time and Rate Dependency of Friction Based on Critical State Theory

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Numerical evaluation of the behaviour of rock discontinuities whose response is governed by faults and joints requires constitutive laws that take into account the various features of the discontinuities. Recently, the elucidation of included fault movement associated with the development of deep underground spaces has become a challenge. It is important to take into account the frictional change of discontinuities in the evaluation of such mechanisms. However, there is no constitutive law for the stress-displacement relationship of discontinuities that can reproduce the time and rate dependency of friction, which is strongly related to the mechanism of earthquake generation. In this study, the constitutive model for rock joints based on the critical state theory is extended to an overstress-type constitutive model that can take into account the effects of time and rate dependency of friction on the shear behavior of the rock joints.

*Poster* 09

# Temperature effect on bentonite deformation behavior

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During the initial phases after closure of a high-level radioactive waste repository, the temperature of the buffer material will increase. Therefore, fundamental properties regarding the temperature dependence of bentonite, which is the main material of the buffer material, have been tested. In this study, two tests were conducted using a consolidation test device that can control temperature conditions. One is a cyclic loading and unloading test under temperature conditions from room temperature to 80 C. The second is a temperature rise and fall test from room temperature to 80 C under stable loading condition. It was clarified that large deformations occur in the specimen under high temperature conditions, that the deformation associated with temperature changes is affected by the past stress path, and that irreversible deformation occurs under normal consolidation conditions.

*Poster* 10

# Rotary crushing & mixing (Twister) Method

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“Twister Method” utilizes high-speed rotary chains within a cylinder to crush 2-3 types of materials into fine particles while uniformly mixing them. This method surpasses conventional techniques in its ability to handle a wider variety of local materials due to its superior mixing and crushing capabilities. It can process large quantities in a short time, with the largest model achieving a processing capacity of approximately 1,500 $m^3$ per day and 270 $m^3$ per hour. Additionally, plant specifications can be modified to meet site requirements. The method is particularly effective in uniformly mixing cohesive soil, which other methods like the backhoe method cannot achieve. Compared to traditional moisture reduction methods such as air drying, the “Twister Method” saves time, cost, and labor. By efficiently utilizing previously wasted local materials, it also reduces environmental impact and costs. The method can crush and mix rocks up to 200 mm in diameter, making it possible to repurpose locally generated limestone and concrete waste. Furthermore, it can crush and mix solidified clay and soft rock to produce uniform improved soil, reducing the need for additives like cement.