PROCEEDINGS OF THE 13TH ASIAN REGIONAL CONFERENCE (ARC13)

Editor: Wei Wu, Nanyang Technological University

Organizers & Partners:

INTERNATIONAL ASSOCIATION FOR ENGINEERING GEOLOGY AND THE ENVIRONMENT (IAEG)

PREFACE

The 13th Asian Regional Conference (ARC13) of International Association for Engineering Geology and the Environment (IAEG) was virtually held on 16-18 November 2021 in Singapore.

The ARC series started in 1997 in Japan and has become the premium engineering geology event in Asia and the international engineering geology community. It is held once every two years and hosted by an Asian national group of the IAEG. Countries that have hosted the ARC include China, Korea, Japan, India, Nepal, Indonesia, and Malaysia. ARC 13 is the first time of the ARC series held in Singapore. As Singapore pushes for more use of underground space, engineering geology becomes increasingly important to meet the need for more such engineering capabilities.

ARC13 was jointly organized by Society for Rock Mechanics & Engineering Geology (Singapore) and The Geological Society of Hong Kong. The organizers offered an ideal opportunity and an online platform for professionals from the international engineering geology community to exchange the latest experiences and ideas on engineering geology, particularly on the conference theme "Engineering Geology for Sustainable Resource and Infrastructure Development".

The virtual conference included 7 keynotes, 76 oral and poster presentations, and a panel discussion "Meet the Editors of the journal of Engineering Geology and the Bulletin of Engineering Geology and the Environment." Over 1000 attendees joined the keynote and parallel sessions as well as the panel discussion during the three-day conference. The organizers thank all who were participating in the conference and all who worked hard to make it success: authors, keynote speakers, session chairs, committee members, and all others who supported the conference. The sponsors are also thanked for their generous contributions.

Wei Wu
Chair of Local Organizing Committee of ARC13

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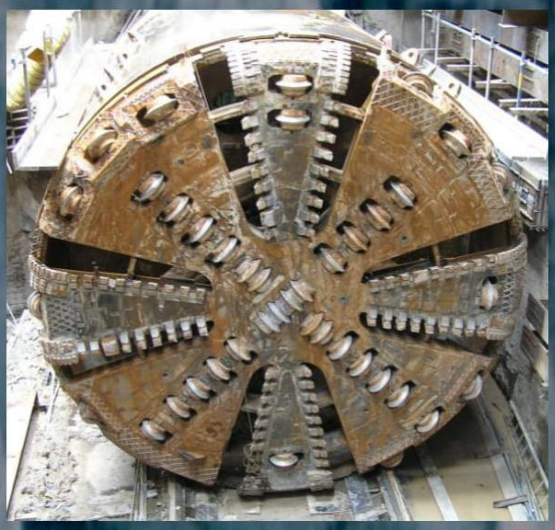

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ABSTRACTS

SESSION TOPIC
T01 - APPLIED GEOMORPHOLOGY AND STRUCTURAL GEOLOGY

ARC13-A-0054 - The Tsiimlyansk Reservoir Neotectonics

Ms Olga Sirotkina %#+ *Lomonosov Moscow State University, Russian Federation*
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The skipping of neotectonic studies of territories with an increasing technogenic load can lead to catastrophic consequences.Research methods based on the relationship between the relief, the tectonic structure and neotectonic movements provide objective material of the relief development in neotectonic time and make it possible to separate active and passive structures to identify dislocation zones.The research was carried out in the area of the Tsimlyansk reservoir, where important engineering objects are located power plants and the Volga-Don shipping canal. The purpose of this research is to study the latest structural plan of the territory, identify active structures, the latest deformations and determine the degree of their inheritance for planning engineering and economic activities.For the study the structural-geomorphological method (SGM) was used. It supposes the analysis of the relief in horizontal and vertical sections according to different-scale topographic maps. In addition, the method of automated search for linear image elements and the calculation of their statistical characteristics implemented in the LESSA program was involved. The initial information was the GMTED2010 digital elevation model with a resolution of 7.5 arc seconds. To determine the current geodynamic activity of the region, seismic, geodetic and geophysical data have been studied.Fracture structures according to geological and geophysical data are grouped into mutually perpendicular systems of the diagonal and common Donbass directions.As a result of the relief analysis in the study area the neotectonic structures of different levels were identified, coupled with "weak zones" (faults, rocks fracturing). The identified blocks are mosaically located on the area, the main directions of their strike are sublatitudinal, northwestern, in the east submeridional. Ring structures and their fragments can be seen to the west of the Tsimlyansk reservoir.The lineament analysis clearly establishes the fragmentary manifestation of regional faults. The groups of local lineaments that define the modern relief have been found, most of them have directions from west to north and from north to east. This direction coincides with the general direction of regional faults. Two regional lineaments were revealed, subparallel to the ancient Losev zone and structures of the Dnieper-Donets paleorift.

SESSION TOPIC
T02 - SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

ARC13-A-0016- Experimental Study of Tight Reservoir Rock Failure Process by Acoustic Emission

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Prof Hongkui Ge *China University of Petroleum, Beijing, China*
Prof Tiantia Li *Xi'an Shiyou University, China*
Dr Xiaoqiong Wang *China University of Petroleum, Beijing, China*
Dr Ke Gao *Southern University of Science and Technology, China*

A fundamental problem in hydraulic fracturing is to understand the mechanism of failure process of tight reservoir rocks. Rock failure is generally caused by the propagation of fractures under the influence natural cracks. Since acoustic emission (AE) technique has proven to be an effective tool to monitor the dynamical fracture propagation, here, AE is employed to investigate the different rock failure processes under uniaxial compression. The experiment rock samples are sampled from four tight reservoirs in typical oil and gas production fields in China. The C7 and LCG tight sandstone are respectively collected from the Ordos Basin and the Junggar Basin. Both the LJP shale and LMX shale are obtained from the Sichuan Basin but with different formations. We analyze the characteristics of acoustic emission data and discuss the relation between acoustic emission parameters and the rock failure process. The results demonstrate that on experimental scale the natural fractures contained in these rocks have distinct impacts on fracture propagation. The AE rate curves indicate different failure patterns, and the RA-AF (RA value and Average Frequency) values of AE reveal that the final shear failure is caused by tensile fracture accumulation. For the vertical-bedding samples, we barely observe shear phenomena accumulated by tensile cracks. While for the parallel-bedding samples, it is common that the tensile cracks could gradually accumulate into shear failure. Additionally, the b-value before the final failure is closely related to the natural crack activation, and the b-value during the final failure signifies the complexity of the fracture network. The b-value could reflect the formation of the fracture network under the joint effects of stress and natural cracks. Specifically, in stress dominated failure process, the b-value is high before the final failure and decreases thereafter. When the failure is controlled by both the natural cracks and stress, the b-value is low before the failure and increases after that. While when the natural cracks dominate the failure process, the b-value is generally within a low level during the whole procedure .

ARC13-A-0035-An Experimental Study On The Effect Of Waste Tire Rubber Particles On Shear Strength Characteristics Of Loes

Mr Rongsen Zhu %+ *Northwest University, China*
Prof wan-li xie # *Northwest University, China*
Ms Hui Yang *Northwest University, China*

With the development of automobile industry, the detriment of waste tires to human beings and the environment is gradually increasing. How to deal with them harmlessly or even make rational use of them has become a global concern. The purpose of this paper is to explore the influence of waste tire rubber particles in improving the geotechnical characteristics of loess, and discuss the possibility of its application in slope engineering and subgrade engineering. Taking the particle size and content of rubber particles as variables, a series of ring shear tests were carried out on loess samples mixed with rubber particles. According to the shear strength of soil samples under various combinations, the optimal selection under different working conditions was obtained. In addition, scanning electron

microscope (SEM) and computed tomography (CT) scanning tests were used to analyze the microstructure of the samples, including the contact relationship between rubber particles and soil skeleton particles, and the effect of rubber particles on the change of pore type, so as to explain the macro behavior of soil from the micro point of view.

ARC13-A-0038-Mechanics Characteristics And Microstructure Evolution Of Fiber-reinforced Collapsible Loess From The Chinese Loess Plateau

Ms Hui Yang [%+] *Northwest University, China*
Prof Wanli Xie [#] *Northwest university, China*
Dr Rongsen Zhu *Northwest University, China*

The porous structure of loess can not be eliminated fundamentally by banded and mesh reinforcement materials. Fiber as homogeneous material with holistic structure and isotropy. Fiber-reinforced loess is widely used to achieve three-dimensional reinforcement technology, especially polypropylene fiber (PP fibers) reinforced materials. In this paper, polypropylene mesh fiber and rod fiber are selected as the improved reinforcement materials for collapsible loess from the Chinese Loess Plateau. The effects of the two fibers on the mechanics characteristics of the stiffened loess were investigated by triaxial tests. Fiber length and fiber incorporation amount were selected as control variables to study the optimal fiber length and fiber incorporation amount to effectively improve the strength of collapsible loess. Samples before and after triaxial tests were selected for further scanning electron microscope (SEM) and computed tomography (CT) scanning tests. The interaction between loess and different polypropylene fibers was investigated from the microscopic point of view, that is, the microstructure evolution characteristics of soil-geosynthetics interaction. The strengthening mechanism of PP fibers on collapsible loess strength is clarified, and the optimal scheme of fiber-reinforced soil is determined. The microstructure evolution characteristics showed that the PP fibers can effectively reduce the porosity of loess.

ARC13-A-0069-Effect of Initial Water Content and Dry Density on Soil Water Characteristics of Compacted Soil

Ms Yu Wang [%#+] *Chang'an University, China*

In order to investigate the effect of initial water content and dry density on the soil water characteristics of the compacted soil, the loess used as filling in the Land-making Project of Yanan new district in China was collected and compacted to two series of samples: one is the same dry density but different initial moisture content, the other is the same initial moisture content but different dry density. The SWCCs of all samples in the range of 0 ~ 105 kPa were measured by the filter paper method. The measured data are fitted with the Fredlund; Xing equation for each dry density. For the samples with different initial water content, the SWCCs show significant differences in the range of 100 ~ 1000 kPa: the retention capacity of water will increase with the initial water content below the range of plastic limit. For the samples with different dry density, The SWCCs show prominent differences in the suction range below 100 kPa while overlapping above this suction. Those suggest that SWCCs of compacted soil with the same dry density are not exactly the same, the effect of initial water content should be considered; and the SWCCs in the high suction range are independent on dry density of compacted soils with the same initial water content, while correlated in the low suction range. This study provide support for further investigation on the unsaturated behaviors of the compacted soil.

ARC13-A-0072-Stress-strain, suction variation and critical state characteristics of Q3 undisturbed loess under constant water content

Mr Lin Zhang %#+ *Chang'an University, China*
Prof Tonglu Li *Chang'an University, China*
Ms Cunli Chen *Xi'an University of Technology, China*
Ms Yan Li *Chang'an University, China*

Constant moisture content is an important aspect of geotechnical engineering tests. In order to investigate the stress-strain，suction change and critical state characteristics of Q3 undisturbed loess from Lanzhou, China under constant water content, the GDS unsaturated triaxial instrument with controllable drainage conditions was used, and the pore-water pressure, axial stress and strain of the undisturbed loess with different initial suction during the isotropic compression and triaxial shear tests were measured. The analysis of the test results shows that: the greater the initial suction of the isotropic compression test, the smaller the compressibility and the greater the degree of suction reduction; the greater the isotropic stress, the greater the degree of saturation increase; the stress-strain curve of triaxial shear test is hardening type, the deviator stress has little effect on the decrease of suction, and mainly affects the increase of saturation; the critical state lines of undisturbed loess with different initial suction in q-p plane are parallel straight lines, and the critical state line of deviator stress and effective average stress can be expressed uniquely by the critical state line of saturated soil; with the increase of the initial suction，the critical state lines of unsaturated soil in e~lgp' plane moves up parallel，and the relation between their intercept and the initial suction is hyperbolic, the slope of the critical state line of saturated soil in e~lgp' plane is obviously smaller, nevertheless the relationship between the ratio of critical void ratio of unsaturated soil (under different initial suction) to saturated soil and failure saturation (or gas saturation) can be expressed by a normalized exponential function.

ARC13-A-0077-Microscopic Deformation Analysis of Unsaturated Loess with an Extended Discontinuous Deformation Analysis Method

Mr Qiang Li %#+ *Chang'an University, China*
Prof Tonglu Li *Chang'an University, China*

Using numerical method to investigate the micro property of unsaturated loess is helpful for the understanding of its physical mechanical behavior. However, some obvious differences were observed between the microstructure constructed by the existing numerical models and the real microstructure of loess, and it is very challenging for these existing models to take consideration of the change on the hydraulic property of the soil produced by deformation. Therefore, we try to establish a model to consider the microstructure of loess and the capillary force based on the discontinuous deformation analysis (DDA). In our model, four key steps are adopted in the construction process of the microstructure of loess. Firstly, a shape database was constructed based on the geometries of a large number of skeleton particles of loess. Secondly, some particles were selected from the shape database according the particle size distribution curve of loess. And then，these particles are dropped into a sample box. Finally, the capillary force at certain water content is calculated according to the Young-Laplace equation, and applied on the wetted surface of two adjacent particles based on extending DDA. This model was used to conduct confined compression numerical tests on loess with three different water contents, and the simulated result is compared with the experimentally measured compression curve to validate the method. Moreover, the model reflects the micro evolution of pore during the compression of unsaturated soil. The soil deformation at micro-scale is majorly generated by large pores; the deformation pattern is concerned with the moisture, namely, the pores are mainly shrunk at low water content while mainly disintegrate at high water content. This research proposed a new numerical model to explore the mechanism of deformation behavior of unsaturated loess.

ARC13-A-0117-Tests on Mechanical Behavior of Cement-treated Masado Under the Influence of Acidic Environment and Temperature

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Prof Feng ZHANG *Nagoya Institute of Technology, Japan*
Dr Hiromasa IWAI *Nagoya Institute of Technology, Japan*
Mr Ittetsu OHARA *Nikken Sekkei Civil Engineering, Japan*
Mr Keigo TAKAGI *Nagoya Institute of Technology, Japan*
Mr Tomoya IWATA *Nagoya Institute of Technology, Japan*

Cement-treated Masado (CTM), as a common cement-mixed geomaterial, is usually only used in ground improvement for temporal structures in Japan. However, in recent years, it has been used for newly constructed permanent structures, such as the supporting ground of pile foundations and direct foundations. The long-term stability of CTM has not been thoroughly investigated, since that it has the risk of exposure to changes in acid environment and temperature, which are very common in volcanic areas in Japan. In this study, to investigate the influence of acidic environment and temperature on the mechanical behavior of CMT, a systematic test program using triaxial tests was conducted on CMT specimens under different conditions of acidic environments, temperatures, and confining pressures. To avoid the extra influence of water on the mechanical behavior of CMT, a special double-cell was designed within the pressure chamber of the triaxial loading device, so that the volumetric strain of the specimens completely sealed with gum sleeve can be accurately measured in triaxial compression and creep tests. Combined with the influence of the initial confining pressure, the influence of the acidic environment and temperature on the strength and dilatancy of CMT is carefully investigated. In addition, the chemical components of all the tested specimens are investigated by X-ray fluorescence spectrometry analysis to identify the calcium leaching in the curing period. Based on the test results, a relation between the stress ratio at the critical state and the influential factors, including the initial confining pressure, acidic environment and temperature, is proposed by regression analyses.

ARC13-A-0124-Creep Behavior of Intact Loess Followed Unloading Paths

Mr zhenxiao li %#+ *Northwest University, China*

Several high-fill projects are carried out on the Loess Plateau, China, accompanying the progressive failure of slopes due to excavation. The compelling need requires a deep understanding of variation in the creeping behaviors of intact loess exposed to unloading. A series of creep tests of intact loess were performed under two separated unloading paths: decrease in confining pressure at constant deviator stress and decrease in confining pressure at axial stress. The results demonstrated that axial deformation followed the first unloading path always appears as compression. While the three forms of axial deformation followed the second path, depending on the applied axial stress level. At a low unloading stress level, the elongation of axial deformation was observed. At a relatively unloading stress level, the axial deformation of the soil experienced the first elongation and then compression. At a high unloading stress level, the axial deformation appeared as compression, and finally, failure occurred with the increase of the unloading stress level. The failure approach index was introduced to use as the criterion for the loess to transform from stable to accelerated creeping. Finally, a modified Burgers model was proposed to characterize the creeping behavior of intact loess followed unloading paths. There was a good comparison between the calculated and measured data of the soil that establishes the rationality and validity of the proposed model.

ARC13-A-0138-Circular Shaft Construction Using Vertical Shaft Sinking Machine (VSM) in Singapore's DTSS2 Project

Dr Aung Ko Ko Soe [%#] *DTSS2 Department, National Water Agency, PUB, Singapore*
Ms Lai Lynn Woo *DTSS2 Department, National Water Agency, PUB, Singapore*
Mr Cheng Boon Ng *DTSS2 Department, National Water Agency, PUB, Singapore*
Ms Angela Ong *DTSS2 Department, National Water Agency, PUB, Singapore*
Mr Venkatesa Perumal *DTSS2 Department, National Water Agency, PUB, Singapore*
Mr Guo Hao Lim [+] *DTSS2 Department, National Water Agency, PUB, Singapore*

Shaft constructions are required in the Deep Tunnel Sewerage System Phase 2 (DTSS2) project at designated locations along the tunnel alignment for the launch and retrieval of Tunnel Boring Machines (TBM) and for the operation and maintenance of the used water conveyance system. Some of the shafts in the upstream stretch of the tunnel are to be constructed in heavily built-up urban areas. Therefore, shaft excavation sites are bounded by commercial/residential buildings, schools, hospitals, transportation infrastructures, major utilities services etc. In addition, hydrogeological profiles at shaft locations are challenging due to the presence of soft clay layers, permeable soil and highly to moderately weathered fractured rock along the depth of excavation horizon. Hence, it is very likely to cause surrounding ground to settle and overstress the foundation system of the existing structures in close vicinity if ground water level draws down or pore pressure drops due to seepage flow into the shaft or stress relief despite a good ground water management system is put in place. Since these existing structures/services are very sensitive to ground movement, it is of paramount importance to keep construction impact and associated geotechnical risks to a minimum. Since shaft excavation by Vertical Shaft Sinking Machine (VSM) has proven advantages and benefits over conventional shaft excavation methods, especially with rapid sinking rates and maximum safety and environmental control, the VSM method is proposed to construct five of the shafts in Contract T-11 of DTSS2 Project. This is the first known use of VSM for shaft construction in Singapore and currently 3 out of 5 shafts have been successfully constructed with this technology. This presentation outlines the background of the method used and intends to share the design approach, challenges encountered, benefits gained, and lessons learnt based on DTSS2 experience.

ARC13-A-0141-Geotechnical and Leaching Characteristics of Marine Clay-cement-incineration Bottom Ash Mixes

Mr KAI GUO [%#+] *Nanyang Technological University, Singapore*
Prof Wei Wu *Nanyang Technological University, Singapore*

A huge amount of incineration ash is generated daily from municipal solid waste (MSW) incineration plants worldwide. In Singapore, most of the incineration ash is disposed at Semakau Landfill, whose capacity cannot meet our increasing demand of waste disposal. This study reports a method to use MSW Incineration Bottom Ash (IBA) as a partial replacement of the ordinary Portland cement in deep cement mixing for soil improvement. We investigate the geotechnical and leaching properties of soil-cement-IBA mixes and assess the toxic element concentrations in dry mixes and groundwater. Our results show that this method is feasible in terms of uniaxial compressive strength, leaching concentrations of heavy metals and other elements, as well as estimated toxic element concentrations in dry mixes and groundwater. The partial replacement of the cement with IBA slightly reduces the short-term strength of the IBA and cement treated soil but slightly improves the long-term strength. The heavy metals can be immobilized effectively in the solidified soil-cement matrix. The reduction in the short-term strength is due to an increase in total porosity with higher IBA content, while the growth in the long-term strength is related to an increase in gel porosity associated with hydration reaction. This method is possible to offer an alternative safe IBA disposal and meanwhile to reduce the dependence on imported cement in resource scarce countries (like Singapore).

ARC13-A-0163-A Coupling Method of Distinct Lattice Spring Model and Beam Finite Element Model for Collapse and Stability Analysis of Foundation

Mr Zhe Li %+ *Tianjin University, China*
Prof Gao-Feng Zhao # *Tianjin University, China*

In this work, the distinct lattice spring model (DLSM) is further developed for handling geotechnical problems. The DLSM is proposed for analyzing material failure and crack propagation. The DLSM is a kind of discrete element method, it represents materials by a system of discrete particles interacting via springs, can naturally predict deformation and collapse of soil correctly without any special operation. To ensure safety, supporting structure is widely applied to resist large deformation of soil. However, the dimension scale of the supporting structure is usually much smaller than it of soil. It;s unsuitable for DLSM to directly analyze structure and soil together as a full 3D model. Therefore, the structural element, beam finite element, is adopted to model the structure. Meanwhile, a method to couple the DLSM and the beam is developed. The beam has 6 degrees of freedom (DOF), 3 DOFs for displacements in x, y, and z axes, and 3 DOFs for rotations around x, y, and z axes. In DLSM, only 3 displacement DOFs are used. To solve this mismatch, one beam node connects to several DLSM particles interacting via normal springs. The cross-section features of the beam are considered in this model. The coupling method is based on the translation of force, the bending moment transfer is handled by the coupling method as well. Based on this coupling method, the cross-section naturally affects the interaction without any other redundant operations. The central difference method is used in the beam integration, which is the same as that in the DLSM. The beam and the coupling method get verifications via some classical boundary value problems. The results show that the algorithm has good accuracy and robustness.

SESSION TOPIC
T03 - ROCK MECHANICS AND UNDERGROUND SPACE

ARC13-A-0001-Seepage Analysis for Rock Tunnel Construction Based on Analytical Methods

Dr Jianping Sun %#+ *CCCC-SJ PTE LTD, Singapore*
Ms Lanting Wu *China Communications Construction Company Limited (Singapore Branch), Singapore*

Rock tunnel/cavern excavation involves high risk of unforeseen ground conditions. One of the risks is the chance of hitting the water bearing zone. And rock grouting is considered as the most efficient method to reduce the water inflow. To determine whether rock grouting is needed, the probing should be carried out first. If the expected water inflow from probe hole is larger than the allowable maximum water inflow, the grouting will be carried out to achieve the strict requirement on the water inflow. After grouting, check hole(s) will be drilled on the same face and same length as the grouted hole. If water inflow is still higher than threshold value, grouting procedure will be repeated until to achieve the grout target. Although many researchers conducted studies related to water flow into subsea tunnel and rock grouting, the knowledge on the practical execution is still limited. Based on other researchers; work, the analytical solutions of water flow for each step of subsea tunnel construction (i.e. probe hole, tunnel before grouting, tunnel after grouting and check hole) have been derived.;Based on the study on these analytical solutions, the key findings are summarized as below: 1. The variation of water flow in probe hole is within 3% when the probe hole diameter increases from 48mm to 60mm, which means there is little influence of probe hole diameter change on the water flow into the probe hole. 2. The variation of water flow into probe hole can be up to 25% when the water pressure in probe hole increases from 0m water head to 12m water head, which means it is important to measure the water pressure and water flow quantities simultaneously. 3. There is a linear relationship for the water flow between probe hole and tunnel, which tally with the actual practice. 4. Decreasing the permeability of the grouted zone contributes to a decrease of the water inflow. However, when the permeability of the grouted zone decreases to a certain value, the water inflow is no longer decreased significantly, which tally with the practical experience.

ARC13-A-0012-Fracture Process Zone Features of Three Granites Under Mode I Loading: Insights from Acoustic Emission and Thin-section Observation

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Dr Louis Wong *The University of Hong Kong, Hong Kong SAR*
Ms Xinyu Xiao *The University of Hong Kong, Hong Kong SAR*

Fracture process zones (FPZs) often develop in front of crack tips preceding the initiation of macrocracks subjected to loading in rocks. However, the effects of mineralogy and texture of granites on the FPZ features are very complex and not entirely understood. In this study, we experimentally study the FPZ features of three granites of comparable mineral composition, but with different grain sizes, namely fine-, medium- and coarse-grained granites (gf, gm, and gc respectively) in mode I semi-circular bending tests. The development of FPZs is monitored by continuously recording the acoustic emission (AE) during the test. The fully-developed FPZs (FD-FPZs), which refer to the FPZ status immediately before the initiation and propagation of macrocracks, are characterized by the spatial distributions of AE events. To investigate the microcracks features, a postmortem microscopic study is conducted on the thin-section samples of the specimens after loading tests quantitatively. The results show that for the FD-FPZs of the gf and gm, the AE event number decreases exponentially with the distance away from the notch central plane along the principal tension stress direction, and the AE event number decreases nonlinearly with the distance for the gc. The locations of the maximum AE event points are consistent with those of the maximum microcrack density along the same direction for the gm. In terms of the energy distribution of the AE events characterizing the FD-FPZs, the gf is

comparable with that of gc, which is different from the energy distribution of the gm. This experimental study reveals the complex effects of mineralogy and texture on the FD-FPZ development of granite under mode I loading.

ARC13-A-0063-Evaluation Framework of Underground Space Resources of a Costal Soft Soil City: with Shangha as an Examplei

Prof Wang Jianxiu %#+ *Tongji University, China*
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Multi-layers interbedded with sand, silt, clay and clayey soil are symbols of many coastal cities, such as Shanghai. Multi-aquifer multi-aquitard system is formed under the geological conditions. Soil and sediment with different depth and different lithology type fit for different purpose. How to evaluate the quantity and quality of the underground space is vital for the urban sustainable development. With Shanghai as an example, the evaluation frame work including both quantity and quality evaluation method is suggested. Quantity evaluation system considering developed and utilized resources, non exploitable resources, partially exploitable resources and fully exploitable resources was established. Quality evaluation system considering structural stability, engineering geological condition, hydrogeological condition, geological hazard, building height, development depth, underground resources were established. Finally, with Chenghuangmiao Temple strict as example, the evaluation frame was used and checked to provide reference for future city underground space plan.

ARC13-A-0074-Determination of on Fracture Toughness of Mode I Fractures from Three-point Bending Tests at Elevated Confining Pressures

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Fracture toughness is one of the key parameters for the characterization of brittle rock fracturing. Yet, constraints on it mainly rest on measurements performed at ambient pressure, although rock fracturing frequently occurs at elevated pressures even in geotechnical applications. To address the lack of a generally accepted evaluation procedure for tests at elevated pressure we explored the conditions for initiation and propagation of mode I fractures in samples subjected to bending at elevated pressure by numerical modelling and analytical considerations of the involved angular moments. We derived an evaluation procedure and applied it to experimental observations for specimens with either a chevron or a single-edge notch of four different rocks (a granite, a limestone, a marble and a sandstone) subjected to three-point bending at confining pressures up to 30 MPa. Two sealing methods were considered. Specimens were either varnished or jacketed by a rubber tube, differing in whether pressure is allowed to build up inside the pre-fabricated notch or not, respectively. Irrespective of notch geometry and sealing method, the determined toughness values increase significantly with confining pressure. The apparent toughness determined for jacketed specimens is, however, larger than that for varnished specimens, for which toughness seems to reach a plateau with increasing pressure. The similarity of the pressure dependence of the toughness determined for varnished, i.e., uniformly pressurized, samples with that of other physical properties suggests that it is controlled by the closure of pre-existing micro-cracks; the absence of pressure dependence beyond some tens of MPa suggests

that non-linearity effects may not be as severe at depths beyond a few kilometres as previously discussed. Our study points to the necessity of resolving numerical issues associated with compressed fractures and of further improving experimental facilities for the determination of fracture toughness at elevated pressure.

ARC13-A-0108-The Influence of JRC and Surface Geometry on the Mechanical/Hydraulic Aperture of 3D Printed Joints

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Prof Jia-Jyun Dong [#] *Graduate Institute of Applied Geology, National Central University, Taiwan*

We conducted discontinuity logging and estimated Geological Strength Index (GSI) of the Neogene-Paleogene sedimentary and the Cretaceous igneous rock core samples taken for an offshore wind farm project off the Kyushu (Southwest) region in Japan. Bottom-fixed foundations, namely jacket type foundations are planned for wind turbines. Whilst there have been few cases where the GSI system is applied to onshore projects as well as offshore projects in Japan, we attempted to employ the GSI system to characterise the rock foundation for offshore wind farms instead of Japanese conventional rock mass classification system proposed by Central Research Institute of Electric Power Industry (CRIEPI). This study compares the GSI values estimated from different approaches with Rock Mass Rating (RMR) calculated based on Bieniawski (1989) and the CRIEPI rock mass class to discuss the applicability of the quantitative GSI system to offshore wind projects in Japan. The rock mass strength and deformation modulus were calculated from the estimated GSI values and unconfined compressive strengths (UCS) obtained by laboratory tests on intact rock based on the Hoek-Brown criterion. We propose a quantitative approach of GSI = 90/70 x (R2+R3+R4) - 5, modified from Song et al. (2020), where R2, R3 and R4 are the ratings for RQD, the spacing of discontinuities and the conditions of discontinuities respectively in the RMR system since it has a good correlation with qualitative GSI values. The GSI values generally range from 25 to 70, which are equivalent to the range of 35 to 80 in RMR values. The GSI values of each CRIEPI rock mass class generally agree with the typical ranges suggested by Cai et al. (2002); however, the estimated GSI values tend to be larger. Whilst equivalent Mohr-Coulomb friction angles derived based on Hoek et al. (2002) tally with a typical range presented by Yoshinaka et al. (1989), equivalent Mohr-Coulomb cohesive strengths vary in a wide range depending on UCS. The rock mass deformation moduli estimated based on Hoek and Diederichs (2006) correspond with those obtained by pressuremeter tests.

ARC13-A-0099-Comparison of Different Approaches of GSI System Applied to Foundation Design for Offshore Wind Farm in Japan

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Fluid flow through rock mass is a critical issue for rock engineering practice and geoscience from shallow to great depth. Among others, the hydraulic aperture (e) of a single joint is a key variable for predicting hydraulic conductivity. Usually, the mechanical aperture (E) of rock joints under different normal stress can be predicted via famous Barton model. If the relation between mechanical and hydraulic apertures is available, the hydraulic aperture at different depth can thus be calculated. In this study, laboratory measurements of mechanical/hydraulic apertures of sawed, polished aluminum samples using gas flow via YOKO 2 system under a confining stress from 3 MPa to 120 MPa were conducted. Different from the widely adopted normal displacement method for measuring the joint

closure, we measured the mechanical aperture from the joint volume divided by joint area, directly. Based on the measurements, we found the relationship between hydraulic and mechanical apertures is non-linear. The traditional assumption of linear relation between mechanical and hydraulic apertures could not be valid under a wide spectrum of confining stress, even for a smooth joint. Our measurement shows a contradict trend to the widely used non-linear relation between E/e and e. We argue that the estimation of initial aperture for converting joint closure curves into mechanical aperture for normal displacement method accounts for the contradict trend. Joint apertures (e and E) cannot totally close even when the effective normal stress goes up to 120 MPa (~5 km). The residual hydraulic and mechanical apertures of smooth aluminum joint are about 1416 µm and 33-37 µm, respectively. Finally, we demonstrated clearly that the influence of matrix (intact rock) pore volume on joint volume measurement is significant even for low porosity granite sample (porosity < 1%) and the matrix permeability contributes few to the measured hydraulic aperture.

ARC13-A-0105-The Relation Between Hydraulic and Mechanical Apertures of Smooth Joint Under Low to High Confining Pressure

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Characterizing rock joints' hydro-mechanical behavior is critical for rock engineering because joints frequently act as weak planes and fluid paths of the rock masses. Among others, joint roughness directly controls the mechanical and hydraulic behaviors of rock joints. The Joint Roughness Coefficient (JRC) has been widely used to quantify the joint roughness for four decades. This parameter was incorporated into empirical equations to predict the joint closure under stresses and fluid flow characteristics as well. However, the validity of using one single parameter to represent the complex geometry of joint surface could be an interesting topic to be explored. This study creates numerous smooth joint samples (including matched and mismatched joints) with similar JRC (2-4) but different surface geometry via 3D printers. The mechanical and hydraulic apertures (E and e) of the printed joint samples under different normal stress were measured using high confining stress, permeability/porosity measurement system (YOKO2). The relation between joint closure (related to E) and fluid flow characteristics (related to e) can be quantified. The testing results show a significant influence of joint surface geometry on the E-e relation; even the JRC is roughly the same. The role of geometry heterogeneity of real rock joint surface on the hydro-mechanical coupling needs further study.

ARC13-A-0119-DEM Simulation Of Transversely Isotropic Rocks Under True Triaxial Stress Condition

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The response of transversely isotropic rocks under true triaxial testing is studied using the discrete element method (DEM). Numerical rock specimens of four different orientations of beddings (i.e. β = 0o, 30o, 60o, 90o) are created and three series of test simulations (i.e. σ3 =10, 50, 100 MPa) are conducted on each of the rock models, with five different values, ranging from σ2 =;σ3;to σ2;=σ1;stress states. The impact of the bedding orientation and the intermediate stress on the peak strength and degree of anisotropy are subsequently explored and explained through underlying micromechanics. An ascending then descending variation of the peak strength, in form of a fan-shaped; curve, is noted against σ2. The initial ascend is because of the increase in stress asymmetry, reducing the number of failure planes, as well as the suppression of

sliding of weak planes, while the strength eventually descends as σ2;becomes large enough to induce cracks in the pre-peak region. Similarly, varying degrees of tilting; of the fan-shaped curves for the different bedding orientations are noted. This is owing to the difference in the degree of suppression of the weak plane slippage, indicating the effect of β on peak compressive strengths. The U-shaped variation of peak strength with anisotropy angle is also observed that flattens under higher σ2;values, due to the suppression of the slipping of weak planes, indicating the reduced effects of anisotropy when σ2;is increased. For numerical models of Posidonia Shale under σ2;normalized by σ*, which is the conventional triaxial compression strength obtained for β = 0o at a specific state, the anisotropy effect, in fact, ceases to influence when σ2;/ σ* is higher than 0.76. This study, hence, provides a comprehensive understanding of the mechanical behavior of anisotropic rocks under polyaxial stress conditions. The data and findings from this study can be utilized in not only evaluating the effectiveness of various proposed failure criteria but also modifying or formulating a new failure criterion for rocks that can model the effects of both polyaxiality and anisotropy together.

ARC13-A-0125-Thermal Effects on Heterogeneity and Anisotropy of Spatial Distribution of Microcracks in Granite

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The rock is subjected to thermal action in high-temperature rock engineering. The thermal action induces the generation of microcracks in rock due to the differences in thermal expansion properties of minerals. Quantitative characterization of microcrack characteristics is important for understanding the thermally induced deterioration mechanism of rock properties. The parameters, such as length, width, area, volume and porosity, were generally introduced to quantitatively describe the microcrack characteristics in previous studies. To further quantitatively describe the spatial distribution characteristics of the microcracks, in the present study, two indexes (heterogeneity coefficient and anisotropy coefficient) were proposed based on the micromechanics Computed Tomography (CT) experiment. The two indexes were used to quantitatively describe the heterogeneity and anisotropy of spatial distribution of microcracks. Moreover, the effects of heating temperature (from 25 to 1000 °C) and thermal cycling number (from 0 to 16 times at 500 °C) on the heterogeneity coefficient and anisotropy coefficient were further discussed. The results show that both the heterogeneity and anisotropy of thermally treated granite increase to their maximums as temperature increases to 500 °C and then significantly decrease to constants as temperature further increases. For the specimens subjected to thermally cycling treatments at 500 °C, both the heterogeneity and anisotropy increase significantly after the first thermal cycle, after which the heterogeneity and anisotropy change slightly as the cycling number further increases. The proposal of the heterogeneity coefficient and anisotropy coefficient realizes the quantitative characterization of the spatial geometric characteristics of the microcracks.

ARC13-A-0126-Investigation of Stress Wave Propagation Through Rock Masses with Double-scale Discontinuities by a Split Three Characteristic Lines Method

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The study of stress wave propagation in natural rock masses is significant for the dynamic stability of rocks. Discontinuities ranging from micro-defects to macro-joints are widely existing in natural rock masses, which have a significant effect on stress wave propagation.Currently, the traditional methods

have been successfully applied to stress wave propagation through single-scale discontinuous rock masses. The stress wave propagation through the macro-jointed rock masses can be solved by the two characteristic lines method combined with the displacement discontinuity model (DDM). In addition, practical rock masses are generally micro defected, which can be equivalently described by a viscoelastic medium. The traditional three characteristic lines method was developed to solve the stress wave propagation through the micro-defected rock mass. Because the effects of micro-defects and macro-joints in rock mass on stress wave attenuation of velocity and amplitude are different in the mechanism. Therefore, it is still difficult to analyze the stress wave propagation through double-scale discontinuous rock masses containing micro-defects and macro-joints. To solve the stress wave propagation through rock masses with double-scale discontinuity, a split three characteristic lines method combined with DDM was proposed in the present study. The three characteristic lines are split at the location of a single macro-joint. So that the split three characteristic lines are divided into three basic elements: triangle, diamond, and separated diamond elements. Similar to the traditional three characteristic lines method, the triangle, and diamond elements are used to solve stress wave propagation at left boundary points and ordinary interior points of the rock mass. To further study the stress wave propagation at the macro-joint, the separated diamond element is proposed. The DDM is introduced into the separated diamond element to solve wave propagation at pre-interior points and post-interior points of the macro-joint. The results show that the present method can be used to investigate the stress wave propagation through double-scale discontinuities efficiently.

ARC13-A-0147-Measuring the Mechanical Parameters of Fragmented Earth and Asteroid Rocks with Micro-rme

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Mr Yiheng Zhang *Wuhan University, China*
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Measuring the mechanical property of rocks accurately is critical, however, in many situations, it is challenge to obtain intact and standard rock specimens required by macroscale rock mechanics experiments (macro-RME), such as MTS tests. For example, the rocks are frequently fragmented and muddy inside faults, which leads to the difficulty of drilling and sampling. The phenomenon of core disking also widely exist due to high-stress. Additionally, the future extraterrestrial human activities, such as resources exploitation and base construction on Mars, need the aid of geotechnical engineering technology. Currently, there are only two approaches for humans to obtain the rock samples beyond Earth: sample-return activities by spacecraft and meteorite investigation. Meteorites are rare, expensive, small in size and arbitrary in shape, so it is difficult to process them into standard rock samples required by traditional macro-RME. In this paper, a technique is developed to measure the mechanical property of small and any-shaped rocks based on microscopic Rock Mechanics Experiments (micro-RME), in order to investigate granites and NWA13618 meteorites. First, using nanoindentation tests, the elastic modulus of rock-forming minerals is measured. Then, with the results of micro-RME, the upscaling modelling method is developed to get the macroscale mechanical property of these rocks.

ARC13-A-0151-Estimating the Mechanical Properties of Complex Fractured Rock Masses Using Machine Learning

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Natural rock masses contain randomly distributed fractures and exhibit complex mechanical behaviors. These fractures may interact with filling materials (e.g., soil, water, and ice) and behave even more complex. The estimation of fracture parameters in present failure criteria is often subjective and may not be reliable to predict the mechanical properties of fractured rock masses. Here, we present a random forest model to predict the mechanical behaviors of granite specimens with ice-filled fractures. Due to difficulties in collecting fracture parameters from invisible granite in the laboratory and the field, we employ a two-dimensional particle flow code model and validate this model using the uniaxial compression test results of intact and fractured granite specimens. The numerical results show that the persistence factor and the inclination angle significantly influence the uniaxial compression strength and the Young;s modulus of the frozen fractured specimens, while the influences of the fracture number and the ice layer thickness are less important. We collect the uniaxial compressive strength and the Young;s modulus from 186 uniaxial compression tests on the frozen fractured specimens with different ice layer thicknesses, inclination angles, persistence factors, and fracture numbers. We use these parameters to train the random forest model and predict the uniaxial compression strength and the Young;s modulus of frozen fractured specimens with random number and geometry of ice-filled fractures. The prediction results outperform the uniaxial compression strength and the Young;s modulus obtained from the Hoek-Brown failure criterion and the Ramamurthy criterion. Our study indicates that machine learning method can be a reliable option to estimate the mechanical properties of complex fractured rock masses with randomly distributed fractures filled with various materials.

ARC13-A-0153-Coupled THMC Modeling on Acidizing Process in Fractured Carbonatite Geothermal Reservoirs

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Chemical stimulation, as a soft stimulation method, has been increasingly used in geothermal reservoirs because of its low risk of induced seismicity. A nonreactive fluid is first injected to connect natural fractures with hydraulic pressure, followed by injecting acid to etch fracture walls. The main aim of this study is to further develop a fully coupled thermo-hydro-mechanical-chemical (THMC) modeling framework for chemical stimulation in carbonatite geothermal reservoirs containing a system of intersecting fractures. A nonlinear constitutive models for rock fractures are included in the present modeling framework. The developed modeling framework is verified using a case study of chemical stimulation in the geothermal well, Xiongan New Area, China. The simulation results indicate that the injection of high viscosity nonreactive fluid significantly increased the apertures of pre-existing fractures and resulted in some tiny shear sliding of fractures within 10 meters from the wellbore. There was no obvious fault slip induced, which was consistent with the results from microseismic monitoring. Fractures with high initial aperture and strick parallel to the direction of maximum horizontal principal stress are easier to be stimulated. The sensitivity analysis of acid concentration, injection rate, perforation depth and direction are also carried out to provide an optimal solution for local acidizing acid fracturing design.

ARC13-A-0154-Shear Behavior of Direct Shear Test for Natural Open Fracture and Infilled Fracture

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Filling materials in fracture significantly affect the mechanical behaviors of single rough rock fractures, but the difference of natural open and infilled fracture during shear has not been entirely understood and requires further investigation. In this study, direct shear tests were performed on the Beishan natural open and infilled granite fractures, respectively. The evolution of asperity damage during shear was monitored using acoustic emission (AE) technique, and the asperity degradation zones and damage volumes caused by shear were evaluated with the 3D blue light scanner. A laser diffraction particle size analyser was used to examine the size distribution of sheared-off fragments. The results showed that the shear strength of infilled granite fractures is larger than that of natural open fractures under a lower normal stress because of the cohesive strength, which is different from most artificial fractures with unconsolidated infilled materials. With the increase of the normal stress, the shear strength of open fracture may exceed that of infilled fracture. The size of the sheared-off fragments in both kinds of fractures under different normal stresses was found to follow a Weibull distribution but particle size tended to be smaller in infilled fracture. Combining the proposed joint damage coefficient and the Weibull size distribution of the sheared-off fragments can approximately predict the potential effects of sheared-off fragments on solute retardation coefficient for infilled fractures. The acoustic emission ringing count and accumulated AE energy of two kinds of fractures follow the same law but tend to be more drastic in open fracture, which complain the two main modes of asperity degradation during shear, i.e., instantaneous failure of asperities occurring at the peak shear stress, and crushing of the generated fragments with further shear displacement.

ARC13-A-0158-Intelligent Identification of Lithology and Adverse Geology in Tunnelling

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Lithology variation zones and adverse geology often cause serious disasters in tunnelling. It is necessary and important to develop non-destructive, in-situ, fast and intelligent means of identification methods for lithology variation zones and adverse geology, so as to take corresponding countermeasures in advance to reduce and prevent geological disasters. Here we report and demonstrate some recent progress on deep learning-based methods for intelligent lithology and adverse geology identification in tunnelling. These methods are based on in-situ data collection (non-lab environment), deep learning and fusion analysis of images, element and mineral data of rocks. The proposed methods were successfully applied in some tunnel engineering and can also be used in similar surface geological surveying and subsurface mining and logging analysis in underground projects.

ARC13-A-0159-A New Simulation Method for Grouting Process in Karst Fractures and Conduits: the Sequential Flow and Solidification Method (sfs Method)

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Time-dependent viscosity characteristics of quick-setting slurry grouting lead to uneven distribution of viscosity in the slurry diffusion zone. At present, there still lacks reasonable and effective slurry-water interaction analysis method to reveal the diffusion behavior of quick-setting slurry in dynamic water of karst fractures and conduits. A Sequential Flow and Solidification (SFS) method was proposed, taking the spatial-temporal evolution of slurry viscosity into account. In addition, the validity and necessity of the SFS method were verified. Based on the SFS method, the slurry diffusion process under different flow velocities in a fracture was analyzed and the effects of flow velocities on the changes of

the grouting pressure, the counter-flow diffusion distance, and the down-flow diffusion behavior were explored. The applicability and the feasibility of studying the slurry diffusion mechanism in a wide-open fracture on an engineering scale were determined. The SFS method is also applied to the numerical investigation of dynamic grouting and blocking of flowing water in karst conduits. It achieves the visualization of dynamic grouting in the conduit, and explores a reasonable and effective method for dynamic grouting via the flow control technology. The outlet flow, the loss rate of slurry, the distribution laws of velocity and pressure inside the conduit during plugging are furtherly analyzed. In addition, the mechanism of flow control on dynamic grouting and plugging of the large-flow karst conduits is revealed. Moreover, the results were applied to the large-scale water inrush control project of Hejing Limestone Mine, China. The SDS method can be used to simulate the dynamic water grouting process, providing an improved method for the simulation of permeation and compaction grouting.

ARC13-A-0162-A Coupled Thermo-mechanical Distinct Lattice Spring Model for Numerical Modelling of Rock Thermal Fracturing

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Rock thermal fracturing is a key issue in the analysis of geothermal development, oil and coal seam gas exploitation, strong electromagnetic wave assisted rock breakage, nuclear waste storage, crustal evolution, etc. The effect of thermo-mechanical coupling is crucial to the propagation and evolution of rock thermal fracturing. Distinct lattice spring model (DLSM) is a discrete element method that discretizes matter into individual particles linked by springs, which has advantages in simulating the dynamic failure and wave propagation in rocks. Nevertheless, it still lacks the ability to deal with multi-physics coupled problems. In this work, the concept of thermal pipe network is adopted in the DLSM to duplicate the corresponding mechanical lattice so that the Fourier;s law can be solved at the pipe level. In addition, the implementation of thermal pipe network in the DLSM is convenient to develop the coupled thermo-mechanical constitutive model for rock failure and to derive the closed form relationship between the macro and micro thermal parameters. The coupling relationship between the thermal and mechanical fields is addressed through the thermal expansion equation. Furthermore, the coupled thermo-mechanical DLSM adopts a dual timeline coupling scheme that the mechanical timeline and thermal timeline can have different time scales, which enables the coupled model to both deal with the transient and steady-state thermo-mechanical coupling problems. Finally, we demonstrate a series of numerical examples to verify the applicability of the coupled thermo-mechanical DLSM.

SESSION TOPIC
T04 - SITE INVESTIGATION AND GEOLOGICAL MODEL

ARC13-A-0002-Determination of Fluvial Sand Layer Using CPTu Test Results for an Underground Project in Singapore

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Ms Lanting Wu *China Communications Construction Company Limited (Singapore Branch), Singapore*
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A deep excavation was carried out at eastern part of Singapore which was 50m wide and 20m deep based on the dimension of permanent structure. Steel pipe pile wall were proposed as the retaining wall. Typical soil profile consists of 10m to 16m thick of reclaimed Fill, 7m to 32m thick of Kallang Formation (Fluvial SAND and CLAY and Marine CLAY) and competent Old Alluvium of varying weathering degree. There was potential risk of the ingress of water into excavation if the pipe pile interlock was not grouted when fluvial sand was encountered. Therefore, the fluvial sand layer shall be determined by soil investigation.The cone penetration test (CPTu) allows for a continuous soil profiles and can collect independent readings in a single sounding. These readings, notably the cone tip resistance (qc), sleeve friction (ft) and penetration pore water pressure (u2) are interpreted to give the soil parameters used to assess subsurface stratigraphy. Since both the penetration resistance and sleeve resistance increase with depth due to the increase in effective overburden stress, the CPTu data requires normalization for overburden stress. And normalized soil behavioral type (SBTn) chart proposed by Robertson (1990) is commonly used. Another parameter, Soil Behavior Type Index Ic, is also commonly used to represent the SBT zones in the SBTn chart. Furthermore, Robertson (2010) proposed a simplified relationship between soil permeability and Soil Behavior Type Index, Ic and this relationship is used in this study.A series of cone penetration (CPTu) tests were carried out and Ic was obtained based on normalized cone resistance and normalized friction ratio. Then the permeability was estimated using the relationship between soil permeability and Ic, and the fluvial sand layer was determined when the permeability is higher than 10-6 m/s. Finally, the interpretation of CPTu test results was used in the design successfully.

ARC13-A-0025-A Review of Methods for Measuring Dynamic Characteristics of Fault Gouge

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Prof Yong-Seok Seo *Chungbuk National University, Korea, South*

The methods for measuring P- and S-wave velocities were reviewed to obtain the dynamic characteristics of fault gouge, calculated from the P- and S-wave velocities. Ultrasonic tests employ a higher frequency source than in seismic surveys, which can reduce the accuracy of the measured data via scattering and attenuation losses in porous fault gouge. Borehole surveys, such as down-hole, up-hole, and cross-hole surveys, as well as suspension P-S (SPS) logging, measure the velocities of the surrounding rocks, including fault gouge. The measured velocities can also be somewhat high or low due to the borehole casing, which is installed to prevent the collapse of weak fault gouge in the borehole wall. Seismic survey using direct waves and multichannel analysis of surface waves (MASW) surveys were conducted on a trial basis to obtain the dynamic characteristics of fault gouge. The elastic wave velocities from the seismic survey are reliable based on the first arrival calculations, and the S-wave velocity was verified by identifying the polarity reversal. Meanwhile, a low S-wave velocity was measured during the MASW survey. It is regarded as the reason why the analyzed surface wave was produced in a near-surface zone that contains different geological structures like faults, which lower the S-wave velocity by inducing the reflection of ground roll.This research was supported by Basic

Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2021R1I1A1A01040298).

ARC13-A-0089-Application of a Three-dimensional Quality Control System Based on Permeable Fracture Information in a Dam Foundation Process

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Ms Takako Miyoshi *Kajima Corporation, Japan*
Dr Kazuhiko Masumoto *Kajima Corporation, Japan*

In order to control the quality of the dam foundation processing, it is important to grasp the three-dimensional permeability in the foundation rock mass. As grout slurry infiltrates through the fractures in the rock mass, the quality should be evaluated by the permeable fracture information (its intensity, orientation and continuity) and construction data. However, since it requires a lot of time and labour, it is necessary to quickly extract information on rock permeability from the data obtained in the grouting process and to construct a system for easy evaluation and management. Focused on the image of borehole wall during grouting, we developed a technique to automatically extract fracture information and to quantitatively evaluate the three-dimensional continuity of fractures, using the image analysis and AI technique. Furthermore, as this fracture information is integrated with the construction information, the quality of dam grouting could be evaluated as a three-dimensional quality control system. This paper shows the results of application of this quality control system with the actual constructing dam site.

SESSION TOPIC
T05 - SLOPE STABILITY AND LANDSLIDES

ARC13-A-0062-Glaciers, Sediments and Lineaments – Temporal, Spatial, Environmental and Structural Constraints for the Evolution of the Dangkhar Landslide, Himachal Pradesh, India

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Prof D. Scott Kieffer *Graz University of Technology, Austria*

With an estimated volume of approximately 15 to 20 km³, the Dangkhar Landslide located in the Spiti Valley, Himachal Pradesh, India, is one of the largest landslides on earth. Its initiation is geochronologically constrained to have occurred during the late Pleistocene and may be related to glacial retreat following last local glacial maximum around 20,000 years ago. There is significant value in understanding the causative factors contributing to such an enormous and rare event. On the basis of comprehensive field studies and laboratory investigations, it is concluded that erosional, structural, and depositional features within and surrounding the Dangkhar Landslide are critical for understanding landslide initiation and its long-term behavior.;The landslide developed as a block slide along a synformal flexure, and through-cutting lateral valleys fulfill the kinematic conditions for creating a massive removable block of earth. Deposits of weakly cemented and crudely bedded carbonate breccias in the landslide;s toe region represent depositional activity during recession of the main valley glacier, and cross-cutting structural relationships involving ground ruptures (lineaments) and rock glaciers in the head region record long-term, ongoing landslide deformations subsequent to its initiation. Stable isotope signatures of samples indicate presence of freshwater associated with the formation of breccia deposits.;While many details concerning the timing and development of the Dangkhar Landslide remain unknown, recent studies illuminate some very important aspects. The glacial history of the Spiti Valley combined with structural kinematics are clearly important factors concerning landslide development. Also important are constraints concerning the minimum age of landslide initiation (20,000 years), and structural evidence documenting long-term ongoing slope deformations.

ARC13-A-0041-Prediction of Landslide Potential Using Steady State Seepage in Unsaturated Soils

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The stability of residual slopes is strongly influenced by climatic and hydrological changes such as precipitation, infiltration, evaporation and transpiration processes. Landslides triggered by rainfall are caused by the buildup of water pressure into the ground. Prediction of rainfall-induced landslides is problematic as it needs a full understanding of flow processes and engineering behaviour of soil within the unsaturated (or vadose) zone. It is generally accepted that the rapid rise of rainfall-induced pore-water pressure is critical to the initiation of slope failures. The loss of matric suction and the advance of the wetting front are controlled by the infiltration characteristics of the slope. An ability to model this process is critical to an accurate assessment of slope stability problems. One way to evaluate the effect of infiltration is to use an analytical formulation for the suction stress above the water table. On the basis of this analytical formulation and the classical infinite slope stability analysis, Lu and Godt (2008) proposed a first-order method for evaluating potentially unstable soil slopes subject to steady surface infiltration. In this paper, a simple practical method based on a modified form of Lu and Godt (2008) is proposed. The method evaluates an average antecedent rainfall intensity that could potentially trigger landslides above the water table. A series of parametric studies were conducted to study the relative importance of soil properties, weathering characteristics, slope geometry, initial water table location in inducing of landslides. Several case studies are presented to illustrate the potential usefulness the proposed framework. The relationship between the predicted rainfall intensity versus observed rainfall intensity for the landslide events shows the reasonable agreement, given the

significant simplifications involved, particularly the estimation of matric suction using steady state infiltration and the vague definition of observed rainfall intensity. The analytical framework proposed in this paper is capable of assessing the likelihood and precipitation conditions that induce the triggering mechanisms of landslides. This analytical framework could form part of a landslide warning system or provide a quantitative basis for landslide risk assessment.

ARC13-A-0067-Mechanism of Resurrection of Ancient Landslides within the Xiaonangou Watershed of Yan'an City

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Yan'an, Shaanxi Province, is located in the middle reaches of the Yellow River, and its unique geomorphology and fragile ecological environment make landslide disasters frequent. Due to the shortage of land resources in the city, people are expanding urban space with a large number of development watersheds, inducing the resurrection of many ancient landslides. The resurrection of ancient landslides poses a threat to soil and water conservation, ecological environment, engineering construction, human and property safety, so it is extremely important to study the resurrection mechanism and propose green management measures. In this paper, we use geological survey, geological mapping and geotechnical investigation to obtain the ancient landslide boundary, stratigraphic lithology and watershed DEM. On this basis, we find that the moisture and soil shear strength in the ancient landslide body increase with depth, and there is a certain degree of decay law of soil shear strength near the sliding surface. Through the processing of remote sensing image data of vegetation in the study area and long-term subsidence and rainfall monitoring on site, it is found that rainfall affects the degree of vegetation cover, and different degrees of vegetation cover make the resurrection of paleolandslides different. Based on the resurrection factors of ancient landslides in the watershed and the results of indoor experiments, the author proposes the resurrection mechanism of ancient landslides in the watershed. This paper can provide an insight to deal with the resurrection of ancient landslides with a watershed as a starting point.

ARC13-A-0085-Retrogressive Landslide: a Bitter Lesson from Cimanggung Landslide of Sumedang, Indonesia

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The Cimanggung landslide occurred on Saturday, January 9, 2021 just after very heavy rainfall. The landslide was a complex landslide showing a change from slide to flow mechanism of debris. It was evidenced that the landslide was not a single event, but at least four landslides occurred as retrogressive developments of the crown. The first landslide with a semi-rotational type took place at 15.30 local time and claimed 8 lives. The second landslide occurred retrogressively at 19:15 and was followed by a debris flow which resulted in the death toll of 32 lives. It is estimated that this second landslide is much larger than the first, from about 20 m crowns with a length of up to 45 m, to 50 m crowns with a debris outflow reaching of up to 120 m. In this case, the third and fourth landslides tended to occur locally in the second landslide scarp.The landslide location has several layers of rock and soil. Those rock and soil layers are lightly weathered breccia tuffs, strong weathered breccia tuffs, residual soils, and landfill. The drainage in upper houses looks ineffective after the landslide. The water flowing through the drainage seeps into the cracks that form behind the landslide crown. Landslide crown is still actively moving backwards (heading east) because the slope conditions are still unstable due to the condition

of the water and constituent materials. The retrogressive landslides which followed by debris flow will be modeled to determine the run-out distribution. The results of this modeling will be used as a reference for the emergency response team to secure similar landslides which followed by debris flow at other locations.

ARC13-A-0086-Landslide Science of the Himalaya in the Consequences of Deep-seated Slope Deformations

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Himalaya Mountains need a comprehensive evaluation of geomorphological evolution of slope to understand engineering geological study of soil and rock in slopes. In the Himalayan region, role played by the deep-seated slope deformations (DGSDs) for the evolution of relief and hillock are fundamental issues of engineering geomorphology and they need to be pointed out in different geological and geomorphological conditions of the Himalaya.Being a geologically young and active Himalayan belt, the Nepal Himalaya is having issues of deep-seated slope deformations. Deep-seated slope deformations and their related large-scale landslides are complex phenomena taking place through a wide variety of mechanisms whose genesis and evolution are controlled by several factors, among which structure, relief, and tectonic and seismic activities have a particular importance. The deep-seated slope deformations have typical morphological elements which help to recognize them in topographical maps and satellite images along with field data. The surface extension of deformation is generally more than 1 square km with thickness of deformed mass ranges around several tens to hundreds of square km. These deformations related large-scale landslides lack a continuous slip or shear surface delimiting the deformed mass. The rate of movement of deformation is slow, happening in past geologic times with long periods of inactivity. But sometimes they might be active after a consequence of earthquakes or extreme rainfall or human interventions. The deformed slopes are often involved in many shallow-seated landslides and have less drainage density.Observations of project sites in the Himalaya have been suggesting that they are highly affected by existing deep-seated slope deformations related large-scale landslides. In Himalaya, site investigations for tunnels and roads do not follow engineering geomorphological study and they are limited to rock mass characterization along with geological and engineering geological mapping only. Engineering geomorphological evaluation of tunneling site before the project commencement can help to reduce project cost and unnecessary delay of the projects using a blaming phrase: “the Geological Issues”. ;Therefore, this paper will highlight the importance of engineering geomorphological study emphasizing DGSDs in the Himalayan region with few examples.

ARC13-A-0110-Landslide Hazard Mapping Using GIS and GANs at Central Parts of Badakhshan Province, Afghanistan

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Landslide awareness especially in areas prone to this naturally occurring geological hazard is of utmost importance. There are several traditional methods that have been employed with successes and failures being part of their nature with a goal to understand and guard against them. These methods are however deemed rather haphazard in this digital world where structure, relationship between

variables, and tractability, are of extreme importance. With central parts of Badakhshan Province, Eastern-North Afghanistan being the focus of our research, this paper attempts to integrate Geographic Information System (GIS) and Generative Adversarial Networks (GANs) in the mapping of landslide hazards within this area. To achieve this, we attained datasets from the Ministry of mines and petroleum of Afghanistan; which can be generalized as landslide preparedness of the populations within and around our study area, and landslide trigger factors. Having accumulated this data, we employed a GAN whose duty was to automatically discover and learn the patterns in input data in such a way that the model can be used to generate or output new examples that plausibly could have been drawn from the original dataset, thereby allowing one to the assess the occurrence of a fake landslide as though it could or had occurred; One would call this predicting the future and preparing for it before it comes. Outputs from the GAN are then exported into the GIS map in conjunction with the actual data to find the best mitigating techniques. From the results we attained, we were able to locate unstable hazard-prone areas, this will potentially aid in environmental regeneration programs whose goal is to initiate suitable and relatively more practical mitigation measures.

ARC13-A-0128-Developing Landslide Susceptibility Map Using Weight of Evidence Method: a Case Study from the Northern Stretch of Arun River Watershed, Arun Tectonic Window, East Nepal

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The Arun River, a transboundary perennial river flows from China to Nepal along with the Arun tectonic window, East Nepal. The Arun River watershed experiences significant slope instability as landslides occur frequently every year. The present study aims to prepare a landslide susceptibility map of the northern stretch of the Arun River watershed. The study area lies on the northern stretch of the Arun River watershed where both lesser Himalayan and higher Himalayan rock units are located. The GIS-based Weight of Evidence method is adopted in this research to identify the landslide susceptibility. Field investigation of the study area concludes that the combination of the following five parameters including topography, hydrology, geology, land use pattern, and intense rainfall with seasonal snowfall, play a crucial role in the landslide events in this region. A landslide susceptibility map is developed incorporating the consideration of the slope characteristics (slope angle, slope aspect, and slope shape), as well as the stream proximity, the stream power index, the lithology, and the land-use practices. The results show that 83% of the past landslides lie within the high to very high susceptibility zone in the map. The present study demonstrates that the development of the landslide susceptibility map could have a significant impact on the landslide hazard risk mitigation and land use management in this region.

ARC13-A-0135-Theoretical and Numerical Simulation Investigations on Rock Block Seismic Movements in the Three-dimensional Space

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Seismic sliding of rock masses is a serious earthquake hazard. Under the action of earthquake loads, rock blocks may move longitudinally downwards inclined surfaces, while the lateral movement also could be significant. In the present work, the seismic movements of rock blocks in the three-dimensional space is studied. On the one hand, theoretical solutions of a single block moving on an incline under seismic loads is derived. On the other hand, the seismic loading function is added to the three-dimensional discontinuous deformation analysis (3D DDA) program that was enhanced by the Contact Theory for block contact detection, and 3D DDA simulation of seismic movements of rock blocks on inclines is carried out. It shows that the theoretical and numerical results of the acceleration, velocity and displacement in the longitudinal and lateral directions of a single block on an incline agree well under various seismic loads parameters (amplitude, phase and frequency) and incline parameters (slope and friction coefficient). Influences of the seismic loads in the three directions (one in vertical and two in horizontal) on the longitudinal and lateral movements of a single block and multiple rock blocks are carefully studied through the theoretical and numerical analysis. This work builds good basis for the further 3D DDA simulation of earthquake-induced rock mass movements and the further investigations of seismic sliding hazard.

SESSION TOPIC
T06 - GEOHAZARD ENGINEERING AND RISK ASSESSMENT

ARC13-A-0026-Probabilistic Landslide Run-out Hazard Evaluation for Quantitative Risk Assessment

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Quantitative risk assessment of landslides requires the probabilistic evaluation of spatial impact of run-out processes. To that end, it is necessary to estimate landslide run-out intensities (e.g., extension, deposition height, velocities) using probability methods, i.e., probabilistic landslide run-out hazard evaluation. In this paper, a general framework is presented to estimate three-dimensional spatial impact probability for landslide run-out. In the presented framework, a continuum mechanics concept-based dynamic numerical model namely Massflow, is used to conduct run-out analyses. However, the proper selection of model input parameters still remains the biggest challenge in the run-out modeling because they are tied to large uncertainties. To systematically quantify those uncertainties, model input parameters are defined as random variables subject to reasonable probability distributions (i.e., prior distributions), and their distributions are efficiently improved through Bayesian inference with multiple-observations (observed deposition heights at different points in the past landslide accumulation area). Then the calibrated distributions (i.e., posterior distributions) can be used as an input with reliability methods to estimate run-out exceedance probability (i.e., spatial impact probability of landslide run-out) of the potential landslide similar to the past landslide, and to produce run-out hazard maps. Kriging-based surrogate models are used to improve the computational efficiency. To illustrate the performance of the proposed framework, we apply it to two successive sliding of landslide CJ#8, which is located in the Heifangtai, Gansu, China. The computed results are used to produce probabilistic run-out hazard maps of maximum run-out intensities exceeding various run-out height thresholds (i.e., 0 m and 1.5 m) and various run-out velocity thresholds (i.e., 1.5 m/s and 3 m/s). The maps can be visualized in a GIS platform, and superimposed on top of the landslide numerical elevation model or satellite image map, making it easy for decision makers to know the areas that may be affected by the landslide. In addition, the computed results can be used for probabilistic vulnerability evaluation in the quantitative risk assessment. Probabilistic risk analyses allow a costbenefit analysis-based prioritization of mitigation strategies and data support for land planning and management.

ARC13-A-0043-The Analysis of Three-dimensional Surface Deformation in Heifangtai Platform Using Ps-insar Technology

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The serious surface subsidence and deformation has occurred due to the long-term agricultural irrigation in the Heifangtai area, as a typical loess tableland, and has induced many loess landslides. However, limited by the observation methods, the research on the three-dimensional deformation characteristics of this area was limited. The surface deformation in the Heifangtai Platform was taken as the research object in this study. The principle of obtaining three-dimensional surface deformation based on PS-InSAR technology was introduced. Besides, based on the deformation data of sentinel-1A satellite in different orbits, the characteristics of three-dimensional surface deformation in the Heifangtai area from 2014 to 2017 were analyzed, and its development trend was predicted. The results

show that the vertical deformation in the middle of the tableland is large, especially in the villages and nearby villages, and the average deformation rate is -20~6 mm/y. Meanwhile, the hazardous area of landslide along the tableland has large vertical deformation. The deformation results of the 9 regions selected show that the east-west deformation in the whole tableland is large, and the average deformation rate is more than 20 mm/y, which is much higher than that in the north-south direction (e.g. -5~5 mm/y). Therefore, there are uneven settlements in the study area. Besides, the surface subsidence in the study area still maintains a slow and accelerated development stage in the short term. This study provides a reference and guidance for the study of the multi-dimensional deformation characteristics of the surface in the prone area of loess landslide induced by irrigation.

ARC13-A-0084-Debris Flow Disaster Preparedness: Learning from 22 February 2018 Pasir Panjang Debris Flow Case

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Landslide followed by debris flow on February 22, 2018 has caused physical and psychological damage to Pasir Panjang village which hard to forget. Residents still frightened by a similar potential disaster in their village. A series of efforts were made to increase preparedness for similar potential disasters. These efforts include modeling the debris flow on 22 February 2018 run-out distribution, carrying out the boundaries of its hazard zones, transfer knowledge on debris flow emergency response. This series of efforts is Institut Teknologi Bandung community service program to apply knowledge in disaster mitigation activities. The results of debris flow numerical simulation model on February 22, 2018 were able to show the distribution of debris material. The model has 0.3 material concentration, 275 thousand m3 debris volume, 26 km/hour flow rate maximum speed, and flows as far as 2.3 km. Based on the results model, the debris flow hazard zones can be determined. The information is used as an analogy for hazard zone in several locations that has debris flow potential in Pasir Panjang Village

ARC13-A-0097-Spatial-temporal Evolution Characteristics of Land Subsidence and Ground Fissure Using SBAS-InSAR: a Case Study of Yuhua Village in Xi'an City

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Since the late 1950s, Xi'an City has suffered from serious land subsidence and ground fissures, which seriously restricted the urban construction and development planning of Xi'an City. In this paper, Yuhua Village, one of the typical land subsidence areas in Xi'an City, is taken as the research area. Based on the SBAS-InSAR technique, three kinds of satellite data (ERS, Envisat, Sentinel-1a) covering the study area from 1992 to 2020 are used. Combined with the drilling data, the history and current situation of urban underground water exploitation and development, this paper analyzes the temporal and spatial evolution characteristics of land subsidence and ground fissures around Yuhua Village, and discusses the genetic mechanism of land subsidence and ground fissures. The main results are as follows: annual deformation rate maps in Yuhua Village and surrounding area from 1992 to 2020 are obtained, and the subsidence center changes from the electronic city (90 mm/a) in the 1990s to the Yuhua Village (50 mm/a). There is a correlation between land subsidence and ground fissures in space-time distribution, and the ground fissures are exposed in the north edge of the ground subsidence trough, and expand according to the development of the ground subsidence trough. The subsidence center of Yuhua Village is still expanding, and the f4 ground fissure may extend westward. The development of ground subsidence and ground fissure around Yuhua Village is affected by the

exploitation of underground confined aquifer and human construction activities. The above results can provide certain reference and theoretical support for urban land development and disaster prevention affected by land subsidence and ground fissures.

ARC13-A-0121-The Dynamic Response Characteristics of Sites with Earth Fissures

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As a widespread geological hazard, the disaster development process of earth fissures is irreversible and difficult to control, which seriously affects the construction and safe operation of engineering facilities. However, few clear conclusions and special regulations have been given regarding the influence of earth fissures on the dynamic response characteristics of a site and earthquake prevention and disaster reduction measures. With the aim of providing previously lacking advice regarding earthquake fortification in proximity to fissures, systematicmicrotremors testing were conducted.The typical earthfissures in the Fenwei Basin were taken as as the research objectand more than 40 microtremor survey lines were laid.In order to reveal the dynamic response of microtremors from several aspects, four methods, including the Fourier spectrum, the horizontal-to-vertical spectral ratio (HVSR), the response acceleration, and the Arias intensity, were employed.Finally, the dynamic response characteristics, influencing factors, ground motion amplification effect, influence range, engineering protection distance and seismic fortification criteria of earthfissure sites are revealed and proposed. The results show that a greater dynamic response can be found near the earth fissure. The amplification effect decreases and eventually disappears with increasing distance from the fissure. A series of amplification attenuation curves were calculated, the empirical equations of various sites were determined and seismic fortification distance were estimated. Research on the dynamic response amplification effect of earthfissure sites will alsoprovide technical support to disaster prevention and mitigationof similar sites.

ARC13-A-0123-Is the Factor of Safety Reliable for Assessing the Stability of Fluid-overpressurized Rock Fractures?

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Fluid pressurization in rock fractures under extreme conditions, such as reservoir impoundment and hydraulic fracturing, may accelerate the instability of fractured rock masses. Fluid pressure can reduce the effective normal stress on rock fractures and cause the degradation of the shear strength, resulting in destructive geohazards. Recent evidences show that the factor of safety (FOS) defined by the traditional methods may not predict the stability of rock masses appropriately. In our study, laboratory experiments, numerical simulations, and theoretical derivation are conducted to investigate the effect of fluid pressure distribution on the FOS assessment. We find that the Mohr-Coulomb failure criterion is inapplicable to predicting the instability of low-permeability fractures under significant fluid pressure gradients, and the FOS evaluated based on the failure criterion can be much higher than 1. The more considerable the fluid pressure gradient, the higher the FOS at fracture failure. Thus, a significant fluid pressure gradient may cause the premature failure of a rock fracture. Our analysis also indicates that the upper bound of the FOS at fracture failure under a non-linear fluid pressure gradient depends on the initial FOS of the fracture without fluid pressurization. The findings help advance the understanding of rock mass instability due to fluid pressurization and the safety control of rock engineering projects under extreme conditions.

ARC13-A-0146-Geohazards and Human Settlements: Lessons Learned from Multiple Relocation Events in Badong, China – Engineering Geologist's Perspective

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Prof C. Hsein Juang *Clemson University, United States*
Prof Janusz Wasowski *National Research Council, Italy*

Mountainous regions are inherently susceptible to geohazards, such as landslides and debris flows, with the threat of natural disasters compounded by human activities (mainly settlements). Lessons learned from past events that involved the interactions between human activities and geohazards are helpful for future site selections of human settlements in mountainous regions. To this end, the events associated with county seat relocations in Badong, a typical county in the Three Gorges Reservoir region, China, are studied from an engineering geologist's perspective. Over its history, the county seat was relocated multiple times, with the first relocation traced back to the Song dynasty (960-1279 A.D.) and the last two relocations linked to the Three Gorges Dam project. By studying geohazards and their interactions with human activities in these county-seat relocations, and through the reconstruction of these events, we secure insights into decision-making for these events. As part of the reconstruction of these relocation events, we analyze a giant pre-historic landslide, whose discovery ultimately prompted the third relocation. Using the case history of this landslide, we also discuss and emphasize the importance of proactive monitoring of geohazards for disaster resilience enhancement, recognizing that our knowledge of nature is vastly incomplete.

ARC13-A-0148-Debris Flow Management along the National Highway in Korea

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In Korea, there are about 70% of mountainous areas and most landslides are rock failure. Nevertheless, debris flow sometimes occurs due to heavy rain. Debris flow occurs in the blink of an eye, the damage area is very large, so it is highly likely to cause casualties, so systematic management is needed. The management of debris flow was strengthened nationwide in the wake of the landslide at Umyeonsan Mountain in Seoul, but CSMS(Cut Slope Management System project by Ministry of Land, Infrastructure & Transport(MOLIT)) did not manage debris flow before 2013. The mountainous area where debris flow occur was under the jurisdiction of the Korea Forest Service(KFS), and road landslides were said to have nothing to do with debris flow. The need for management has emerged as torrential rains caused by global warming have increased the number of debris flow invading roads. In the management of roadside debris flow, there was initially confusion in the management of debris flow and in the setting of survey items. We made several key tasks to solve this issue ; To prepare items and checklists for debris flow field surveys, prioritization of investigation considering risk and damage levels of debris flow, classification of countermeasures to prevent debris flow damage & establishment of a cooperative system between MOLIT and KFS. KFS already operates geohazard map for damage prediction of debris flow and geohazard map for Integration Debris flow, taking into account topography, geology, and population. But this map itself does not take into account roads into account. Nevertheless, we think this map can play an important role in extracting debris flow risk areas along national highway. In 2021, we're going to find and list the overlapping parts of the existing debris flow hazard map and roads. We are going to conduct a joint investigation on the debris flow points where the risk is high and make a countermeasure. Of course, it will be possible to operate the debris flow checklist and investigation priority techniques.

SESSION TOPIC

T07 - SENSOR TECHNOLOGY AND DATA ANALYTICS IN ENGINEERING GEOLOGY

ARC13-A-0009-Study on Soft Subgrade Settlement Via Optical-fiber Bidirectional Zigzag Based on Dofsm

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Soft subgrade settlement has always been a prime factor affecting construction quality in coastal areas of China and other countries. Corresponding settlement and deformation monitoring are very essential, as they can carry out process monitoring for soft subgrade and nearby engineering. Conventional point-type monitoring instruments have the advantages of simple operation, reliable precision, and convenient data processing. However, the point-type sensors are only selectively installed in some locations, resulting in missing inspections, to a certain extent. Recently, distributed optical fiber sensing monitoring (DOFSM) technology has been studied deeply and applied consistently. Its full distribution, anti-electromagnetic interference, corrosion resistance, high precision, and other characteristics can accurately realize laboratory studies and engineering applications. This study designs a novel fiber layout mode with a bidirectional zigzag shape based on DOFSM to monitor the settlement and analyze the results. This work theoretically analyzes the feasibility of settlement and deformation monitoring of soft subgrade using optical fibers laid in a bidirectional zigzag. Then, the optical fibers data are analyzed via the designed bidirectional zigzag layout in the field monitoring study, and traditional point-type monitoring results are compared. The results show that the novel fiber layout in a bidirectional zigzag can theoretically carry out the conversion calculation from strain value to settlement value in monitoring soft subgrade. The settlement values of the monitored area can be obtained through the related calculation in the field monitoring using a theoretical formula. Compared to traditional monitoring results, DOFSM results using a bidirectional zigzag layout can obtain more on-site data, and the results are more accurate and more in line with the actual situation. Moreover, the three-dimensional camber graphics of soft subgrade with optical fibers data are obtained to analyze the changing trends. The results reflect the settlement and deformation trend of soft subgrade during the monitoring period more intuitively. DOFSM, in the form of the bidirectional zigzag layout, can better implement the settlement and deformation monitoring of the subgrade, providing a reference for further study.

ARC13-A-0044-Application Of UAV-based Photogrammetry To Extract Fracture Planes Of Dam Foundation Rock Mass In Japan

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The key roles of dam foundation rock mass are to provide sufficient strength to support dam embankment, and to resist to leakage of water. When considering resistance to leakage of water, it is important to understand the fluid flow within the rock mass. For example, in fractured rock mass, fluid tends to flow through permeable fractures. Therefore, in such case, understanding fracture properties

(size, intensity, and orientation) of dam foundation rock mass is critical in support of dam foundation design. Fracture data are collected through geological surveys including core logging and surface mapping. Although surface mapping such as window mapping allows collection of two-dimensional (2-D) data of fractures, surface mapping typically requires field geologists to manually record geological information and tends to be time-consuming. In recent decade, with the advancements in remote sensing techniques and computer efficiency, there are new technologies to acquire digital field data remotely at shorter time. One example is the application of UAV (Unmanned Aerial Vehicle) based photogrammetry combined with SfM (Structure from Motion) techniques in acquisition of fracture data. Although this technique has been applied to various rock engineering applications, the application to flat rock surface such as dam foundation rock mass has not been examined. This paper studies the application of UAV-based photogrammetry to extract fracture planes from flat rock surface using a case study of dam foundation rock mass in Japan and examines the results by comparing fracture properties. The comparison showed strong agreement between fracture orientations and distributions obtained through UAV-based photogrammetry and window mapping, which implied applicability of the method to dam foundation rock mass.

SESSION TOPIC
T08 - ENERGY EXTRACTION AND STORAGE

ARC13-A-0017-Physical-mechanical and Drillability Characteristics of Ziliujing Conglomerate Formation in Western Sichuan Basin of China

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The conglomerate rock is usually featured by strong heterogeneity, high abrasiveness, and poor drillability due to its complex composition and texture, which brought a huge challenge for drilling efficiency. In order to guide the drill bit selection and high-efficiency drilling, the physical, mechanical, and drillability characteristics were investigated for conglomerate rock that collected from the lower Jurassic Ziliujing formation in the Western Sichuan Basin of China. The mineral composition, SEM micro-structure, P- and S-wave velocities, uniaxial and triaxial compressive testing, drillability, abrasiveness were systematically tested and analyzed. The mechanical properties and anti-drilling ability of Ziliujing formation were proposed for a typical deep well of S-07, and the distribution characteristics were analyzed. The results indicated that the Ziliujing rock is rich-in quartz and clay minerals, due to the co-existing of strong quartz gravel and weak argillaceous cement, the Ziliujing rock shows strong heterogeneity. The relationships are roughly linear among UCS, drillability, and grinding weight loss with P-wave velocity. The Young's modulus, UCS, internal friction angle, drillability, and abrasiveness meet the Weibull distribution pattern, while only the Poisson's ratio meets the Kernel Smooth distribution pattern. The Ziliujing formation has the Young's modulus of 38.61±17.08GPa, the Poisson's ratio of 0.327±0.006, the UCS of 93.02±40.89MPa, the internal friction angle of 49.21±11.00°, the drillability of 8.04±1.54, and the abrasiveness grade of 4.32±1.94. The mechanical properties and anti-drilling ability of logging interpretation are in good agreement with the experimental data. Thus, the Ziliujing formation is a kind of hard rock with strong heterogeneity, high strength, poor drillability, and medium abrasiveness. The physical-mechanical and drillability results can be utilized to guide the drill bit selection and high-efficiency drilling.

SESSION TOPIC

T09 - HYDROGEOLOGY AND GEOCHEMISTRY

ARC13-A-0013-Identification Of Geochemical Anomalies And Target Area Delineation In The Lüliangshan Area, North Qaidam, Western China: Combined Log-ratio Approach And Robust Factor Analysis

Dr Yueming Yin %#+ *China University of Geosciences, Wuhan, China*
Prof Qinglu Deng *China University of Geosciences, Wuhan, China*

In recent years, it was found that identification of weak geochemical anomalies in thick overburden areas is of great economic significance, such as areas thick covered with vegetation, weathering layer or desert. According logarithmic transformation can avoid the closure effect of composite data, logarithmic ratio transformation and robust component analysis (CODA FA) were used to identify the combination of mineralization elements. In Lüliangshan research area, North Qaidam, based on stream sediment sampling geochemical data, it was determined that Cu, Zn and Co have high correlation, and the geochemical mineralization anomalies of single geochemical element Cu, Zn, Co and combined element Cu+Zn+Co were identified by traditional geochemical statistical method and Multifractal singularity analysis (S-A), and potential exploration targets were delineated in this sutdy. It was found that S-A method can not only accurately delineate more obvious anomalies but also more prominent weak anomalies than the abnormal lower limit mean ± 2 standard deviation (mean ± 2STD) of statistical method. And then, the analysis results obtained by statistical method and S-A method were compared with field geological exploration, several copper ore bodies and massive copper mineralization have been discovered in the designated anomalous area that targeted by combinatorial elements anomaly map. Therefore, the target area had considerable accuracy and economic value, it can point out the direction for future exploration of copper deposits in this area. And it can be concluded that the combination of log-ratio approach, Robust compositional factor analysis and Multifractal singularity analysis is an effective method for identifying geochemical anomalies.

SESSION TOPIC

S01 - NUMERICAL AND EXPERIMENTAL ADVANCES IN MULTISCALE FAILURE ANALYSIS IN ENGINEERING GEOLOGY

ARC13-A-0019-Seepage Characteristics of Chemical Grout Flow in Porous Sandstone with a Fracture Under Different Temperature Conditions: an Nmr Based Experimental Investigation

Mr Yuan Zhou %#+ *Wuhan University, China*

In this study, the low-field nuclear magnetic resonance (NMR) testing technique was adopted to experimentally investigate the seepage processes of chemical grout flow in fractured rock mass under various confining pressures and temperatures. The variations in the NMR parameters, including the tested porosity, transverse relaxation time (T2) distribution and T2 peak area were quantitatively analyzed to study the seepage characteristics under different grouting conditions. The changes in the grout viscosity against the temperatures were studied. Then the effects of injection pressures and temperatures on the seepage characteristics of the porous sandstone with a single fracture under constant confining pressure of 20 MPa were systematically investigated. The results indicate that the viscosity of the grout shows obvious time-dependency characteristics and is strongly affected by the temperatures. The flow pattern of the grout is greatly dependent to the injection pressure, whereas it is less affected by the temperature. The permeability of the porous sandstone shows an increase trend as the injection pressure increases and the temperature decreases.

ARC13-A-0020-Numerical Investigation of Coupled Effects of Temperature and Confining Pressure on Rock Mechanical Properties in Fractured Rock Mass Using the Thermal-stress-aperture Coupled Model

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Dr Zhijun Wu *Wuhan University, China*

The mechanical performance of rock mass subjected to the coupled influences of the elevated temperature and in situ stresses has always been a hot topic in underground rock engineering projects. In this study, a thermal-stress-aperture coupled model was first developed and then incorporated into the particle flow code for the coupled thermo-mechanical analyses in fractured rock mass. With thorough considerations of the aperture-dependent thermal and meso-mechanical parameters for the fractured rock, the model performed more realistic thermo-elastic responses of fractured rock to the temperatures and confining pressures. Comparative studies between the numerical simulations and previous experimental results indicated that the proposed model was suitable for modelling the thermo-mechanical behaviors of fractured rock. Then, a series of numerical compression simulations with heating temperatures of 20-600oC and confining pressures of 0-20 MPa were conducted to comprehensively explore the interplay of the temperature and confining pressure on mechanical properties of fractured rock specimens. Finally, the mechanisms that affect the rock thermo-mechanical properties were further revealed. The results indicated that the compressive strength and elastic modulus increase with the increase in confining pressure for each temperature scenario. The thermal strengthening behavior of rock extrapolated to about 400oC takes place in confined compression tests, and is more pronounced at higher confining pressures. The evolutions of thermal properties, micro-cracks and meso-structure are the most decisive factors that could induce the variations of rock properties under the coupled temperature and confining pressure treatment. For analyzing the mechanisms behind strengthening and weakening contribution to rock properties, the positive effect of average fracture aperture variation, the dual effects of increased porosity and thermal-induced micro-cracks, and the negative effect of stress-induced micro-cracks should be comprehensively considered.

ARC13-A-0055-Numerical Modeling Compaction and Dilation Induced Permeability Changes in a Laumontite-rich Tight Rock in Laboratory and Field Scales

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Mr Biao Li *Department of Building, Civil & Environmental Engineering, Concordia University, Montreal, Quebec, Canada*
Mr Sohail Akhtar *Department of Building, Civil & Environmental Engineering, Concordia University, Montreal, Quebec, Canada*
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Laumontite-rich tight rock reservoirs are usually deeply buried and typically have low oil productivity and quickly declining oil rates. Our previous experimental results indicate the compaction/dilation nature of laumontite-rich tight rock under different stress conditions. Designing a suitable hydraulic fracturing scheme to enhance oil production in such laumontite-rich rock formation is challenging. In this study, we applied finite element simulations to study the impact of rock compaction/dilation on overall rock permeability in the lab and field scales. A soft rock plasticity model was applied to characterize the combined compaction and dilation yielding behaviors. The evolution of rock permeability during loading was quantified using the plastic strain result from numerical simulations. Fully coupled flow-deformation finite element simulations were also conducted to study the impact of rock compaction/dilation on well productivity. The possibility of creating a field scale shear band around a hydraulic fracturing well was investigated.Laumontite-rich tight rock reservoirs are usually deeply buried and typically have low oil productivity and quickly declining oil rates. Our previous experimental results indicate the compaction/dilation nature of laumontite-rich tight rock under different stress conditions. Designing a suitable hydraulic fracturing scheme to enhance oil production in such laumontite-rich rock formation is challenging. In this study, we applied finite element simulations to study the impact of rock compaction/dilation on overall rock permeability in the lab and field scales. A soft rock plasticity model was applied to characterize the combined compaction and dilation yielding behaviors. The evolution of rock permeability during loading was quantified using the plastic strain result from numerical simulations. Fully coupled flow-deformation finite element simulations were also conducted to study the impact of rock compaction/dilation on well productivity. The possibility of creating a field scale shear band around a hydraulic fracturing well was investigated.

ARC13-A-0129-Improvements of Using Adaptive Voronoi Mesh in the Rock Fracture Process: Computational Efficiency and Simulation Accuracy

Mr Jiacheng Song %#+ *Southeast University, China*
Prof He Lei *Southeast University, China*

The realization of numerical modeling based on the real structure of rocks is of great importance to study the fracture process and macroscopic mechanical behavior of rocks. One of the major problems in building numerical models based on rock images is that it is difficult to achieve balance between the number of mesh elements and the similarity between the model and the images. Although limiting the number of mesh elements can improve the computational efficiency, the cost of doing so is often the loss of model similarity. The improvement of similarity is mostly achieved by increasing the number of mesh elements, and it does not provide a good representation of the rock mineral grain boundary. Therefore, it is of strong theoretical and practical significance to propose a modeling method that can balance the number of mesh elements and model similarity while providing a good representation of rock mineral grain boundaries.In this paper, various image processing techniques were applied to turn the original rock image into image of feature boundary for post-processing. And then use the gradient descent method to fuse the Voronoi polygon with the rock image according to the characteristics of the pixel value changes in the grayscale map of the rock image. Finally, a high-quality model with a high degree of similarity to the rock image and a relatively compact number of mesh elements is obtained.

This model was then used in the numerical simulation of Brazilian splitting tests, and the final results were in good agreement with the experimental results and showed the advantage of the mesh in reproducing the crack extension of the rock failure process.

ARC13-A-0136-Numerical Manifold Method (NMM) Simulation Study On The Influence Of Heterogeneity On Rock Failure

Mr Qi Lu [%+] *Southwest Petroleum University, China*
Prof Youjun Ning [#] *Southwest Petroleum University, China*

Rock contains different mineral compositions as well as defects like microviods and microcracks, showing significant heterogeneity. Forexample, even for the same batch of rock samples, the deformation and failure experimental results have a certain degree of discreteness. In the present work, based on the conventional Weibull random distribution model of material heterogeneity, the spatial correlation scaling factor of heterogeneity is introduced to build the numerical model of rock with effective description of the heterogeneity of real rock. By selecting different heterogeneity factor (m) values and spatial scale factor (θ) values, the obtained heterogeneity distribution in the numerical models are similar to the spatial distribution and microstructure of actual rock surface images. Thereafter, the numerical manifold method(NMM),a numerical method that naturally represents continuous and discontinuous problems in a unified framework, is usedto simulatethe compression failure of heterogeneous disk and square numerical rock specimens. Results show that with the numerical rock model considering the heterogeneity described by the heterogeneity factor and the spatial scale factor, the discreteness of deformation and failure behaviors of rock can be well reproduced. In the future, the numerical manifold method will be used to further simulate and analyze the effecting mechanism of heterogeneity on the deformation and failure of rock and its engineering significance.

ARC13-A-0143-Numerical Modelling of the CRLD Cable and Its Application in Slope Movement Monitoring

-Dr Wen Nie [%#+] *Hebei University of Technology, China*

Rock excavation is an essential phase in civil engineering projects. To reduce the vibrations and compromise the safety, non-explosive rock breaking techniques have been developed as practical solutions for rock excavations close to residential and populated areas. In this paper, the application of expansive chemical agents in rock excavation for deep foundation construction was analyzed using discontinuous deformation analysis. By introducing the pressure histories as results of expansive chemical agents mixing with water, the progressive rock breakages in moderately weathered granite were simulated. The breaking efficiency was evaluated based on the expansion ratios of the holes and the propagation of cracks in the rock block. Multi-holes patterns were considered to increase the efficiency of the application of expansive chemical agents on site.

ARC13-A-0156-3D Digital Reconstruction of Fractured Rocks and Multi-mineral Rocks

Mr Huaiguang Xiao [%+] *Southeast University, China*
Prof Lei He [#] *Southeast University, China*

Digital rock physics is one of the most important methods to study rock mechanics and permeability properties. This method mainly includes digital rock modeling and equivalent physical simulation. Digital rock modeling is the premise to carry out high-quality equivalent physical properties simulation. Previous research has focused on digital modeling for pore structure in small-scale shales and sandstones. Moreover, the modeling for fractured rocks and multi-mineral rocks is only based on inaccurate numerical models. In order to characterize the 3D structure of fractured rocks and multi-mineral rocks accurately, the 3D discrete fracture network (DFN) and multi-mineral rock digital model are reconstructed from a single 2D surface digital image using the mathematical method. The 3D DFN digital model based on the Markov random field and physical cover method can characterize the geometric characteristics of natural fractures such as aperture, roughness and shape, and the fracture proportion in the 3D model is similar to that in the 2D model. This 3D DFN digital model can provide a reliable reference for analyzing rock permeability and mechanical stability. In addition, the 3D multi-mineral digital model based on the deep learning method can represent the geometry, distribution and mosaic relationship of natural rock grains, and the proportion of different grains in the 3D model is similar to that in the 2D model. This multi-mineral digital rock model also can provide a reliable reference for analyzing the influence of mesoscopic heterogeneity on the macroscopic mechanical response of rock.

SESSION TOPIC
S02 - ENVIRONMENT AND ENGINEERING GEOPHYSICS

ARC13-A-0034-Urban Seismology for Anonymous Monitoring of Urban Activities

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Dr Yunyue, Elita Li *National University of Singapore, Singapore*
Dr Enhedelihai Nilot *National University of Singapore, Singapore*
Ms Yumin Zhao *National University of Singapore, Singapore*
Prof Arhur Cheng *National University of Singapore, Singapore*

Traditional urban activity monitoring based on cameras, although very effective with recent advances in computer vision, raises severe privacy concerns. Urban seismic monitoring, which records vibrations caused by human activity with geophones, has its natural attribute of anonymity. Here, we present a case study demonstrating the use of seismic method to monitor urban activities with less privacy intrusion. We analyze the seismic signals recorded by a group of wireless geophones deployed on the campus of National University of Singapore for the past year. Based on the spectral analysis of the seismic data, we characterize the seismic signals induced by different kinds of human activities, including motor traffic, air traffic and foot traffic. For road vehicles, we observe strong energy across a wide frequency band (0-200 Hz) on their seismic spectrograms, based on which we propose an automatic motor traffic counting algorithm. For airplanes, we observe unique Doppler phenomena in the spectrogram, from which we estimate flight parameters such as flight path, height, and speed. For pedestrians, we observe spiky vibrations caused by footsteps, from which we estimate the cadence information. After analyzing the seismic monitoring data, we observe a clear correlation between the traffic activities leaving the NUS campus and the severity of the government's restrictions during Circuit Breaker and different phases of opening. Our study suggests that the anonymity of seismic method enables high resolution monitoring of urban activity, which provide open and useful information for evaluating the effectiveness of public policies, monitoring local human aggregation, and optimizing the use of public facilities.

ARC13-A-0066-Feasibility Study on Using Recycled Construction Waste Aggregate in Urban Sponge Water Storage Structure

Mr Xue-tong Ma %#+ *School of Geological Engineering and Surveying, Chang'an University, China*
Mr De-bin Gao *School of Geological Engineering and Surveying, Chang'an University, China*
Prof Tonglu Li *Chang'an University, China*

To improve the utilization rate of recycled aggregate and provide safe and reliable building raw materials for water storage structure of sponge City. The particle breakage and settlement deformation of recycled aggregate of construction waste with different proportions under different moisture content and load after long-term drying and wetting cycles were studied through large-scale consolidation test. The results show that the compression settlement of construction waste recycled aggregate is affected by load, moisture content and drying and wetting cycles, and the proportion of aggregate also has a certain influence on the settlement. With the increase of load and the times of drying and wetting cycles, the compression settlement of recycled aggregate increases. With the increase of the proportion of brick aggregate, the compression settlement increases. When the moisture content is the optimal moisture content, the compression settlement is the largest. It can be considered that the settlement of aggregate is mainly caused by particle breakage, and other factors affect the compression settlement by affecting particle breakage. Particle breakage is the fundamental reason for the settlement of recycled aggregate. Based on the experimental results, the empirical formula of aggregate ratio, moisture content, load and settlement under the action of drying and wetting cycles is established. According to the characteristics of water storage structure in sponge City, the appropriate construction scheme is put forward.

Considering that the actual application load of water storage structure is small, the post construction monitoring program is converted to pre construction prediction. In terms of construction feasibility, recycled aggregate is a reliable raw material for the filling of sponge city water storage structures.

ARC13-A-0100-Dynamic Monitoring of Co2 Sequestration and Plume Motion with Advanced Seismic Imaging

Prof Ping Tong %#+ *Nanyang Technological University, Singapore*

Geological storage of CO2 in a deep saline aquifer is a promising way to reduce the emission of greenhouse gas to the atmosphere. This is a critical approach for the success of the Net-Zero 2050 goal set by many major industrial countries. Storage of CO2 requires monitoring of the induced seismicity, the plume extent and the potential stratigraphic seal failure. All of these can be accomplished by using advanced seismic imaging techniques. Seismic traveltime tomography is a routine imaging technique to investigate structural heterogeneities and geodynamics of the Earth's interior. Ray-based seismic traveltime tomography is simple and easy to be implemented. But ray tracing may be inaccurate even in mildly heterogeneous model. Full waveform inversion is physically more correct and maintains its accuracy in complex media. However, a good knowledge of earthquake sources and structure is an essential requirement for the accurate measurement of the misfit between synthetic and observed waveforms. In addition, full waveform inversion is computationally expensive. We present a third form of seismic traveltime tomography, which is neither ray-based nor wave-equation-based. In detail, seismic traveltime tomography is formulated as an eikonal equation-constrained optimization problem, which is solved by the adjoint-state method. For both isotropic and anisotropic media, we discuss adjoint-state absolute traveltime tomography, adjoint-state common-source double-difference traveltime tomography, and adjoint-state common-receiver double-difference traveltime tomography. The advantages of these methods include (1) accurate computation of traveltime fields in complex media, (2) using the most reliable seismic data traveltime, (3) correctly reflecting the relation between the traveltime data and subsurface structure, and (4) the double-difference traveltimes have strong resolving ability of the subsurface heterogeneities. All these imaging techniques will be applied to monitor the dynamics of CO2 storage and plume motion.

SESSION TOPIC
S03 - ENVIRONMENTAL PROCESSES IN GEOTECHNICS

ARC13-A-0114-Physical Disintegration of Mudrock Samples in Hambalang Area, Bogor, Indoesia

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Many of the infrastructure buildings are built on a foundation from sources of mudrock. Hambalang, Bogor, Indonesia is an area that has projected infrastructure buildings, including national sports facilities and housing for residents. Previous reports have stated that construction problems mainly originate from unstable foundation material due to the presence of mudrock and its weathering product. Mudrock can be evaluated for its disintegration characteristics through immersion and drying which minimizes mechanical forces. The research was conducted by testing the physical disintegration of several mudrock samples from Hambalang, to later become an engineering consideration in ongoing or future infrastructure activities. The test is mainly the preparation of rock samples weighing 450-550 grams which are dried in sun exposure for two days. The samples were then immersed in a water-filled beaker for 24 hours. Series of tests for the physical properties of rocks were also carried out to obtain water content, dry density, porosity, and absorption.Based on the disintegration index value that has been obtained, the quantitative approach shows that all samples have a high index. This indicates low disintegration characteristics. This is different when observed physically through immersion tests. The intact sample has mostly deteriorated into angular fragments that show clear evidence of the disintegration of the rock. Further review is needed regarding the characterization of mudrock disintegration in Hambalang. Field observations with visual during immersion observations show similar conditions in the form of disintegrated rocks.

ARC13-A-0142-A Design Concept for Wells Screen During Combined Strata Dewatering with Difference Hydraulic Permeability

Dr Xiaotian Liu %#+ *Tongji University, China*
Prof Wang Jianxiu *Tongji University, China*
Ms Na Xu *Tongji University, China*

With the comprehensive implementation of "deep earth exploration" in China, urban underground space development has been further improved, more and more environmental problems come with groundwater control in deep excavations. Especially in built-up areas, how to balance groundwater level on both sides of foundation pit and control ground settlement become a hot research topic. However, without the guidance of a perfect theoretical foundation, engineers can only explore some foundation pit dewatering design ideas based on personal experience. "Layered dewatering" was firstly put forward in the process of foundation pit dewatering on Yishan Road station of Shanghai Metro Line 9, when obviously hydraulic differences exist between layer ⑤-2 (silty clay) and layer ⑦ (fine sand). However, design concept of wells screen between two connected aquifers with difference hydraulic permeability is still unclear, and usually causes excessive exploitation of groundwater. In this paper, based on the analysis of shallow geological conditions in Shanghai, five kinds of combined strata with difference hydraulic permeability are summarized, and six dewatering design concepts are put forward. Based on the numerical simulation and comparison analysis of foundation pit dewatering design scheme on Biyun Road station of Shanghai Metro Line 14, the optimization design scheme of wells screen structure is put forward, and the total pumping volume of foundation pit is reduced by 13%.

SESSION TOPIC
S04 - ENGINEERING GEOLOGY FOR TUNNELS AND UNDERGROUND CONSTRUCTION

ARC13-A-0059-Sustainable UUS Induced-Land Subsidence and Economic Spatial Planning Model: the Extent Development Impact

Mr Muhammad Akmal Hakim bin Hishammuddin %#+ *Tongji University, China*
Prof Wang Jianxiu *Tongji University, China*

This paper presents the extent impact of urban underground exploration (UUS) induced-land susbidence to economic factors (i.e buildings, land, infrastructures and underground structure) in terms of urban development, spatial model planning towards sustainable development in a developed megacity of Shanghai. Currently, there are no determined integrated researches conducted to understand the correlation of UUS induced-land subsidence with the economic impact despite its significant role in the urban planning and development at large scale. Secondary data are analysed using hedonic pricing method, multiple regression method, correlation cause effect analysis and spatial-temporal analysis. The data are gathered from online databases: Google, Google Scholar, Baidu, ResearchGates, Elseviers and etc. There are more than 100 prominent journal articles have been reviewed for the data synthesis. The time-frame ranges as early as 1960s-90s, 2000s till 2020. The negative spatial corelation hyphothesis of the economic impact and UUS induced-land subsidence has been proven both similar and contradictory in different areas of Shanghai. The findings are (1) most of the land subsidence and economic impact in central bussiness district (CBD) area of Shanghai are still under controlled due to proper UUS technologies, (2) The new development area of Shanghai (North and Southern) has negative correlation due to the UUS induced-subsidence with the economic factors (3) New development areas are prone for future UUS-induced subsidence therefore, the economic impact may be affected without proper planning and underground exploration countermeasures (4) The economic impact of Shanghai has been influenced by many factors and UUS induced-subsidence are becoming the highest impactful factor (5) In the case of developed and rapid continous urbanisation like Shanghai, groundwater is controlled however, further data collection is needed to make comparison with other developing megacity in South East Asia region with rapid land subsidence issues such as Jakarta. As conclusion, these preliminary findings open up for further research work and questions to be conducted to assists future urban planners, geotechnical engineering in the developed megacity like Shanghai as well as making future comparison with developing megacity, e.g. Jakarta in tackling the UUS, land subsidence, economic impact towards sustainable spatial development model and planning.

ARC13-A-0079-An Image Analyzing Method for Quantitative Evaluation of Crack Spacing in Tunnel Faces

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Mr Daisuke Fukushima *Kajima Corporation, Japan*

Appropriate construction of tunnel requires quantitative and immediate evaluation of properties of the face. The properties consist of several factors, such as strength of bedrock, weathering grade, direction of cracks, and spacing of cracks. Traditionally, the evaluation of these factors has been performed mainly by visual observation by civil engineers. The results of the evaluation have been often not quantitative. In recent years, advances in information technology have led to the development of techniques for quantitatively evaluating the strength of bedrock and the weathering grade rapidly. Quantitative measurement of the direction and the spacing of cracks has become possible by applying laser surveying and photogrammetry. However, these techniques are often insufficient for the purpose

of immediately measuring the direction and spacing of cracks on site because it takes more than ten minutes for analysis. Therefore, we have developed a new method to measure the crack direction and spacing of bedrock quickly and quantitatively by image analysis. This method measures the spacing of cracks by the following four procedures: at first, cracks of the tunnel face are extracted from the photograph of the tunnel face based on the difference in brightness; secondly, the image of cracks is divided into small meshes; thirdly, the dominant direction of cracks is detected in each mesh; and finally, the cracks in the mesh are scanned in the direction orthogonal to the dominant direction and spacing of cracks are measured. We applied this method to an actual tunnel face and were able to measure the crack spacing of the face in approximately ten seconds.

ARC13-A-0080-Experimental Study on Evolution Process and Failure Mechanism of Overlying Strata in Coal Mining Based on Distributed Strain Sensing Technology

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Prof Yifei Cui # *Tsinghua University, China*
Prof Bin Shi *Nanjing University, China*
Prof Yan Yan *Southwest Jiaotong University, China*
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The failure of overlying strata in coal mining threaten the safety of roadway and may further induce underground water inrush accidents. Therefore, the deformation monitoring of overlying strata is of great significance. In order to investigate the evolution process and associated failure mechanism of overlying strata under the action of mining, a physical similarity model test was constructed. The distributed strain sensing technology (DSS) and close-range photogrammetry (CRP) technologies were adopted to record the internal and surface displacement information of the model test during coal mining. By comparing the deformation recorded by CRP technology and DSS cables, the feasibility of DSS technology is demonstrated and even though the deformation is small, the DSS technology can still detect strain variation. According to the CRP result, it is found that the deformed area is saddle-shaped in general, forming symmetrical step-shaped fissures at mining face and the initial position of mining. Through analyzing the strain exerts on the DSS cables when the mining face approaches and passes through the installed DSS cables, the deformation characteristics and failure mechanism of overlying strata is addressed and the shear failure appeared at the toe area of key layer may result in the overall collapse of the overlying strata. This study provides practical significance in deformation monitoring and sheds insight into the failure mechanism of overlying strata under coal mining.

ARC13-A-0104-The Log-GSI Method to Estimate GSI from Borehole Data: Application in Snowy 2.0 Project

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Mr Alberto Vanni *Lombardi Engineering Ltd., Switzerland*
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Since its introduction in 1994, the Geological Strength Index (GSI) has become a popular tool to describe the rock mass condition, particularly due to its link to the previously introduced Hoek-Brown failure criterion which allows to estimate the major design parameters for underground excavation projects (shear strength and deformability).The GSI assessment is usually based on the visual inspection of a rock surface (outcrop, tunnel face, etc.). However, in the design process of underground works the available information at project depth is rather contained in boreholes, practically the information needs to be assembled from the recovered rock cores, their pictures and logged information.Among

others, Hoek, Carter and Diederichs in their paper “Quantification of the Geological Strength Index Chart” (2013) have prepared the way for a quantitative evaluation of the GSI, in terms of RQD for the rock mass segmentation and a few alternative ways of describing the discontinuity quality, in terms of Bieniawski's RMR (Jcond89) or Barton's Q (Ja, Jr) system. Whereas the RQD is commonly available from borehole logging, the description of the joint condition is usually a more narrative aspect.We present the experiences during the design studies of the deep tunnels of the hydroelectric pumped-storage project Snowy 2.0 (New South Wales, Australia), in which the GSI was determined from borehole logging and the rock mass strength and deformability parameters were calculated by the Hoek-Brown criterion.The borehole logging was done according to the Australian geotechnical site investigations standard AS 1726-2017. A procedure was developed to translate the descriptions of the joint condition into Barton's Ja and Jr. The GSI was finally determined according to Hoek et al. (2013) and was compared to and validated by directly logged Ja and Jr values and a visual inspection of the rock cores.The methodological approach, its results and a critical analysis are presented and discussed for 3 boreholes of differing lithology and rock mass quality (good, fair and poor). An outlook is given for the further usage of the outcomes in the design process of underground excavations.

ARC13-A-0127-Better Use of Abandoned Oil/gas Wells and Small Lng Stations

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There are a huge number of abandoned oil/gas wells (AO/GW) all over the world, which can be harmful to the environment if not being treated in a proper way, while the corresponding treatment cost could be high. To address this issue in a more economical way, it is proposed to revitalize AO/GW via geothermal energy exploitation. Considering that the bottom hole temperature of AO/GW is usually low and medium, enhancement of the associate thermal performance is in need. It is known that extra heat should be added to facilitate the regasification of liquified natural gas (LNG) in small fuel stations, which could result in a waste of cold energy. Therefore, if it happens that a small LNG station is surrounded by one or several AO/GWs, geothermal energy exploitation and a small-scale gas turbine can be integrated into the regasification process through a binary cycle system, then the geothermal resources from AO/GWs can be better harvested due to larger temperature difference created, and the natural gas produced can be used to generate electricity first before going to the end users. The purpose of our work is to explore the variation patterns of regasification capacity of LNG station in terms of the characteristics of an AO/GWs, including different thermal conductivity of AO/GW structure and the surrounding formation, temperature gradient and depth of formation, and working fluids and the associated circulation velocities. Then a predictive model using system characteristic parameters will be built to evaluate the maximum regasification capacity under given working conditions.

ARC13-A-0137-Design and Implementation of Integrated Monitoring System for Deep Tunnel Sewerage System Phase 2 (DTSS2) Project in Singapore

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Singapore's DTSS2 project comprises 50 km of tunnelling by 19 Tunnel Boring Machines (TBM) and another 50 km of link sewer pipe jacking work at depths between 35 to 55m below the surface to channel used water to a new centralised water reclamation plant to be constructed in Tuas. Deep tunnelling works inevitably cause disturbance to surrounding ground and the DTSS2 construction in built-up urban environments represents a significant risk to existing structures. As such, TBMs used on the project are heavily instrumented to achieve better control in operation. Every work activity is designed to be monitored with arrays of geotechnical instruments and other sensing providing data at all times. The data volume is expected to be large and to efficiently manage and utilise these data, Singapore's National Water Agency, (PUB) devised, procured and implemented an integrated monitoring system known as the Shaft and Tunnel Excavation Monitoring System (STEMS). STEMS is a bespoke web-based data management system configured in accordance with project specifications and requirements. It is designed to streamline continuous progress and production data flows from TBMs, pipe jacking and shaft sinking machines and integrate with various other monitoring data sources, soil investigation data and construction information. After near real time processing, quality engineering data is delivered in a timely manner, with on-the-fly integration tools for analysis and interpretation. In addition to core monitoring features such as data visualization, reporting and automatic alert messaging, the system also computes and presents detailed construction progress and completion status of every shaft excavation and TBM drive. The statistical breakdowns of work activities are also available and therefore data transparency is improved with more reliable delivery and accuracy. Moreover, real-time display of TBM parameters and digitalization of various construction data with centralized storage on a common data server offers instant and convenient access to construction managers, supervision teams and engineers to make fast and correct decisions. The system is proven to be effective for urban tunnelling projects and to positively impact construction efficiencies. This presentation outlines the architecture, functionalities and some key benefits of implementing STEMS in the DTSS2 Project.

ARC13-A-0157-Sprayed Concrete for the 21st Century

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In recent years, fibre reinforced concrete (FRC) has been used in underground construction for sprayed concrete in underground support linings. The evenly distributed fibres contributed to considerable increase in load-bearing capacity, durability and impact resistance. This paper aims to present the definition, design, performance specification and the latest QA/QC test methods of sprayed FRC. The QA/QC requirements will also be in line with the latest Singapore Standard SS 674: 2021 - Design of fibre concrete structures.

SESSION TOPIC
S05 - KARST GEOLOGY AND ENVIRONMENTAL GEOTECHNICS

ARC13-A-0030-Microscale Structural Deterioration of Intact Loess Under Acid and Saline Solutions and Resultant Macroscale Mechanical Properties

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Dr Wenle Hu *Xi'an University of Architecture and Technology, China*
Dr Shaojie Wen *Xi'an University of Architecture and Technology, China*
Prof Md Mizanur Rahman *University of South Australia, Australia*

Chemical contamination not only can cause environmental problems but also lead to a notable change in the mechanical properties of soil. Loess distributed over NW China is featured with metastable structure, and chemical contaminants induced by rapid urbanisation in recent years notably threaten the fragile loess environments. The microscale structural characteristics of the loess and the impacts on the macroscale mechanical properties, when exposed to chemical contaminants, are deemed critical for chemical-contaminated land reclamation. In light of this, the microscale structural characteristics of the loess specimens exposed to acetic acid and sodium sulfate respectively are studied using scanning electron microscopy, X-ray diffraction, and energy dispersive spectroscopy analyses. Further, their macroscale mechanical properties are determined by direct shear tests. The mechanism to lead to the microscale structural deterioration, when exposed to chemical contaminants, is revealed; the corrosion of the cement between particles caused by hydrogen ions when subjected to acetic acid environments and the salt-induced swelling phenomenon under saline conditions play a leading role in the microscale structural deterioration. The resultant macroscale mechanical properties show excellent correspondence with the deteriorated structural characteristics. The findings of this work provide key guideposts for chemical-contaminated land reclamation in NW China.

ARC13-A-0051-Strength Deterioration Mechanism of a Typical Soft and Hard Interbedded Rock Mass in Three Gorges Reservoir Area Under Wetting and Drying Cycling Condition

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Ms Di Wang *Faculty of Engineering, China University of Geosciences, Wuhan, China*
Prof Huiming Tang *Faculty of Engineering, China University of Geosciences, Wuhan, China*
Mr Jintao Kang *School of Qilu Transportation, Shandong University, Jinan, China*
Mr Zhen Meng *Faculty of Engineering, China University of Geosciences, Wuhan, China*
Ms Xiaoxue Huo *Faculty of Engineering, China University of Geosciences, Wuhan, China*
Ms Yuxin Liu *Faculty of Engineering, China University of Geosciences, Wuhan, China*
Mr Shiyu Li *Faculty of Engineering, China University of Geosciences, Wuhan, China*

Due to cyclic reservoir water level fluctuations, rock mass in hydro-fluctuation belt of reservoir bank are subjected to wetting and drying cycles, which is detrimental to the stability of bank slope. In this study, the strength deterioration mechanism of soft and hard interbedded rock mass under wetting and drying cycling condition are investigated by taking atypical sliding-prone rock mass with silty mudstone and argillaceous siltstone interbedded of the Badong formation in the Three Gorges Reservoir as the research object. The degradation equations of strength parameters of silty mudstone, argillaceous siltstone and bedding planes between these two rock types under wetting and drying cycling conditions are firstly established through a series of laboratory experiments. Based on these obtained degradation equations, uniaxial/triaxial compression numerical experiments were then carried out to study the contribution of strength degradations of rocks and bedding plane to the compressive strength degradation of soft and hard interbedded rock masses and its relationship with the dip angle and confining pressure. The results indicate that the influence of strength degradation of rocks and bedding planes on the compressive strength degradation of soft and hard interbedded rock

masses are obviously varied with dip angle, which can be divided into range of controlling by soft rock, range of controlling by combination of soft rock-hard rock-bedding plane, range of controlling by bedding plane and range of controlling by hard rock. The influence of confining pressure on the contribution of strength degradations of rocks and bedding plane on compression strength degradation of soft and hard interbedded rock mass varies with the dip angle, while the confining pressures in a relatively low level used in this study have little impact on the limits of dip angle partitions by deterioration mechanism. Based on the data acquired from the numerical experiments, the equation to estimate the compression strength of the typical soft and hard interbedded rock mass of the Badong formation under wetting and drying cycling condition was developed.

ARC13-A-0160-Characterization of Geological Targets in Karst Terrains with Seismic Arrays

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Globally, the widely extended karst terrains poses great challenges to urban development, groundwater resources, waste water contamination control, and subsurface geotechnical engineering. Narrow down to geotechnical engineering, sinkholes, dissolved channels and networks, caves and voids certainly complicate the design, construction, and maintenance of any projects sited in karst geology. As an indirect and cost-effective approach, the seismic method using both active and passive sources and deployed either on land surface, or in underground in tunnels or boreholes, or even simultaneously on both surface and subsurface, is one of the most powerful tools to provide credible information of karst environments, in conjunction with the direct excavation by drilling, trenching, and tunneling.In this talk I will survey and review the effectiveness of a variety of seismic array configurations and seismic source and wave types for tackling the challenge of detection of differrent geological targets in karst terrains. I will illustrate the arguments with numerical simulated cases. Apparently, surface arrays are most effective for laterally extended features like underground rivers; while vertical seismic profiling (VSP) may by more useful for imaging the vertical conduits. A combination of using surface array and array in tunnels may provide more tightly constrained information for imaging the targets in front of tunnel face. In really the challenge is time synchronization of the subsurface and surface arrays.

ARC13-A-0161-Research Progress of Geological Forward Prospecting with Seismic Method in Hard-rock Tbm Tunneling

Dr Lei Chen %#+ *Shandong University, China*
Prof Bin Liu *Shandong University, China*

More and more hard-rock TBMs are applied worldwide for underground projects in the field of transportation,water conservancy, andmining, etc. However, hard-rock TBM has poor adaptability to adverse geology, such as faults, karst caves and fractured zones. Without identification of adverse geology in advance, TBM tunneling may encounter geo-disasters such as water inrush, collapse and large deformation. Detection of these adverse geologies is an important prerequisite for the safe and efficient construction of TBM tunnels. In this talk, an active seismic method and a seismic while tunneling method will be introduced to address this requirement. For TBM maintenance stage, the active-source seismic prospecting method based on 3D observation method, the velocity inversion and depth-domain migration methods was developed; and for TBM drilling stage, the seismic detection using TBM drilling noise was improved to achieve the real-time forward-prospecting. Both methods can provide imaging of karst caves and fault within 100m ahead. The detection results are directly presented to better guide tunneling.The method has been successfully applied in field, including Yinsong Water Supply Project, the longest tunnel in Asia—Yinhanjiwei Project as well as the longest railway tunnel in China—Gaoligongshan tunnel in Yunnan province, etc. In this talk,

the typical application cases will presented. On-site applications indicate the method can successfully detect major geological structures and effectively protects safety.

ARC13-A-0164-Cross-hole Resistivity Fine Detection Method for Urban Underground Adverse Geology and Its Application

Dr Zhengyu Liu %#+ *Shandong University, China*

At present, the development of Deep-earth, Deep-sea and Deep-space has been taken as a major national science and technology innovation strategy, while the detection of underground space utilization layer is one of the four major objectives for the Deep-earth plan. Several mature detection techniques have been developed for larger-scale adverse geology such as faults and karst. However, small-scale adverse geology such as small boulders, pebbles, dissolution pipes and caves are likely to induce serious urban geological disasters and environmental problems. The fine detection and monitoring of these geology are gradually becoming an urgent need.In this talk, a fine-imaging inversion method and a monitoring method based on cross-hole resistivity method will be introduced, which will effectively solve the needs of fine detection and monitoring of small-scale adverse geology. In terms of fine detection, a multi-scale inversion method based on convolutional wavelet transform has been developed to successfully solve the boundary inscription problem in resistivity inversion. In terms of monitoring and imaging, a dynamic reorganization strategy of monitoring data has been innovated, and data weighting and temporal regularization constraints have been introduced to effectively realize monitoring and imaging of subsurface water transport.The method has been successfully applied in practical projects, including Xiamen rail transit project, Guangxi Cenxi tunnel project, Jilin Yinsong project, Yunnan Dehou reservoir and a number of other vital projects. The field application shows that the method can effectively realize the fine detection and monitoring imaging of underground adverse geology, and effectively protect the engineering safety.