Global FDEM Workshop 2022 – Building the Future of FDEM

Time	Title and Speaker	
09:00 AM - 09:10 AM Eastern Time (US & Canada)	Chair Opening Remarks - Building the Future of FDEM **Giovanni GRASSELLI** University of Toronto	
09:10 AM - 09:50 AM Eastern Time (US & Canada)	FDEM: A Historical Perspective **Antonio MUNJIZA** University of Split	
09:50 AM - 10:50 AM Eastern Time (US & Canada)	HOSS Development and Applications **Esteban ROUGIER, Earl KNIGHT** Los Alamos National Laboratory	
10:50 AM - 11:20 AM Eastern Time (US & Canada)	Y-HFDEM IDE2D/3D – a unique implementation of the combined finite-discrete element method based on GPGPU parallelisation for modelling dynamic fracture of rocks **Hongyuan LIU, Daisuke FUKUDA** University of Tasmania, Hokkaido University	 
11:20 AM - 11:50 AM Eastern Time (US & Canada)	FDEM GPU Parallel Multiphysics Fracture Analysis Software MultiFracS **Chengzeng YAN** China University of Geosciences, Wuhan	

Time	Title and Speaker	
11:50 AM – 12:20 PM Eastern Time (US & Canada)	FDEM modelling in rock mechanics – From academia to industry **Omid MAHABADI, Andrea LISJAK** Geomechanica	 
12:20 PM - 14:00 PM Eastern Time (US & Canada) **LUNCH BREAK**		
14:00 PM - 14:30 PM Eastern Time (US & Canada)	OpenFDEM: a novel object-oriented FDEM kernel for solving multiscale, multiphase and multiphysics problems in rock engineering **Xiaofeng LI** University of Toronto	
14:30 PM - 15:00 PM Eastern Time (US & Canada)	Algorithm Aspects of the Combined Finite-Discrete Element Method: An Overview **Zhou (Alex) LEI** Los Alamos National Laboratory	
15:00 PM - 15:30 PM Eastern Time (US & Canada)	A fully coupled cryogenic thermo-hydro-mechanical (THM) model for frozen medium: theory and implementation in FDEM **Lei SUN** University of Toronto	
15:30 PM - 16:00 PM Eastern Time (US & Canada)	Large deformation process and combined support methods of soft rock tunnel induced by fragment and swelling under high in-situ stresses: an FDEM modelling **Quansheng LIU** Wuhan University	
16:00 PM - 16:30 PM Eastern Time (US & Canada)	Chair Closing Remarks **Giovanni GRASSELLI** University of Toronto	

Register for the FDEM workshop

Antonio MUNJIZA

FDEM: a historical perspective

Bio:

Prof Munjiza has been educated and/or worked in Europe, UK, Japan (Tohoku University), USA (MIT); he has nearly 40 years of research experience in Computational physics including computational solids, computational fluids, continuum based simulations, and discontinuum based simulations. He has invented FDEM and a number of related algorithmic solutions. He introduced the discontinuum assumption as an alternative/complementary to the continuum assumption. He was the first to propose the virtual experimentation as complementing both theory and experiments; virtual experimentation is based on complex Multiphysics simulations - it produces emergent properties and emergent phenomena.

Esteban ROUGIER, Earl KNIGHT

HOSS Development and Applications

Bio:

Esteban Rougier obtained his Doctorate on Computational Mechanics of Discontinua from Queen Mary and Westfield College, University of London (London, UK). His research efforts during his PhD studies were concentrated on the Discrete Element Method (DEM) and its applications to micro and nano-scale systems. Later on Dr. Rougier extended his research interests to the study, implementation and testing of different algorithmic solutions for the Combined Finite Discrete Element Method (FDEM). Dr Rougier has been working at LANL since 2009 where he has specialized on the area of development and implementation of material models for high and low strain rate processes (for geomaterials and brittle metals) and on applying the FDEM method to several different applications, such as: hyper velocity impacts, earth material testing, hydraulic fracturing, underground nuclear explosion containment and glass breakage, among others.

Earl Knight is a Team Leader in the Geodynamics Team at Los Alamos National Laboratory. His research interests include geodynamic modeling, rock mechanical modeling for deep water oil reservoirs and ground based nuclear explosion monitoring

Abstract:

HOSS (Hybrid Optimization Software Suite) is a parallel multi-physics simulation package developed at Los Alamos National laboratory that integrates computational fluid dynamics with state-of-the-art combined finite-discrete element methodologies (FDEM) - consisting of finite element analysis (FEA) and discrete element methods (DEM). HOSS is capable of solving complex problems for a myriad of engineering disciplines, industrial applications, and scientific research. Whether on a personal desktop or high-performance computing clusters, HOSS' parallelization allows it to efficiently handle millions of interacting and fracturing solids and/or particle systems. In this talk I will provide an overview of the development evolution since HOSS' beginnings (2004) along with some key application examples.

Omid MAHABADI - Andrea LISJAK

FDEM modelling in rock mechanics -- From academia to industry


Bios:

Omid Mahabadi is the president, CEO and a co-founder of Geomechanica. He holds a PhD degree in rock mechanics (civil engineering) from the University of Toronto. Omid specializes in development and application of advanced numerical simulation tools to solve rock engineering problems in civil, mining, and petroleum engineering. Omid was the lead developer of Y-Geo FDEM code and the sole developer of Y-GUI and GeoLab DAQ codes. He has authored or co-authored over 40 articles in peer-reviewed journals and conferences and acts as reviewer for many technical international journals and funding agencies in Canada.

Andrea Lisjak is the numerical modelling lead and a co-founder of Geomechanica. His area of expertise lies in the development and use of finite-discrete element numerical methods to investigate failure processes in rocks. He is the recipient of the 2015 Rocha Medal of the ISRM. He holds a PhD degree in Civil Engineering (rock mechanics) from the University of Toronto, Canada.

Abstract:

Numerical modelling of rock deformation and failure poses major challenges, including: presence of heterogeneities and discontinuities (joints, faults), non-linear stress-strain response, and confinement-dependent behaviour. Commonly used numerical tools either ignore stress and deformation (e.g. limit equilibrium method), assume the rock to be continuous (e.g. traditional finite element methods), or represent the rock mass as complete blocks (e.g. discrete element method). The finite-discrete element method (FDEM) overcomes these limitations and makes it possible to study the failure of rock masses with incorporation of complex kinematic mechanisms. To show the application of FDEM, a number of practical case studies in surface and underground mining as well as civil engineering are presented. These applications demonstrate that large displacements and fracturing in discontinuous rock masses can be simulated without using complex constitutive models.

Hongyuan LIU

Y-HFDEM IDE2D/3D – a unique implementation of the combined finite-discrete element method based on GPGPU parallelisation for modelling dynamic fracture of rocks

Bio:

Dr Hongyuan Liu is currently a senior lecturer at University of Tasmania, an affiliate of CSIRO Mineral Resources, a fellow of Engineers Australia, a chartered professional engineer and a member of Australian Geomechanics Society (AGS). Before being appointed as a lecturer at University of Tasmania, he had worked in University of Queensland as a research fellow and University of Sydney as a postdoctoral fellow. He completed his PhD at Lulea University of Technology in Sweden, and Master and Bachelor degrees at Northeastern University in China. His research interest focuses on tunnelling, rock fracturing, and computational geomechanics. He is the founding or primary authors of three comprehensive geotechnical software including both 2D and 3D hybrid finite-discrete element method (Y-HFDEM IDE2D/3D), 3D elasto-plastic finite element method (TunGeo3D) and 2D damage-mechanics and random probability – based finite element method (RFPA2D). In recent years, he has been leading an international team to develop Y-HFDEM IDE2D/3D (https://sites.google.com/view/hfdem/home) for geotechnical applications, which has claimed several national and international awards including the Best Paper Awards in the 3rd and 4th ACCM in 2018 and 2019, respectively; Excellent Paper Award in the 5th International Society of Rock Mechanics (ISRM) Young Scholar's Symposium in 2019; Best PhD Thesis Award by AGS in 2020; and Excellent Paper Award in the ISRM 11th Asia Rock Mechanics Symposium in 2021.

Abstract:

An integrated development environment (IDE) of both two-dimensional (2D) and three-dimensional (3D) hybrid finite-discrete element method (HFDEM) has been developing at University of Tasmania (UTAS) for modelling dynamic fracture of rocks since 2010. The ongoing collaboration between Hokkaido University and UTAS has seen the parallelisation of HFDEM on the basis of general-purpose graphic-processing-unit (GPGPU) and a number of innovative developments since 2017. This presentation will first review the unique features of HFDEM compared with other FDEM implementations around the world, which mainly include novel contact activation schemes, fast convergent local damping, memory efficient contact damping, statistical and grain-based heterogeneities, and extrinsic cohesive zone models besides GPGPU parallelisation. HFDEM is then applied to investigate the dynamic fracture of rocks in both uniaxial and multiaxial split Hopkinson pressure bar testing systems and its application in rock blasting.

Chengzeng YAN

FDEM GPU Parallel Multiphysics Fracture Analysis Software MultiFracS

Bio:
Dr Chengzeng Yan, professor at China University of Geosciences (Wuhan), PHD supervisor, Xiangjiang scholar, was selected as the top 2% of the world's top scientists in 2022. I mainly engage in finite-discrete element method (FDEM) research work. Since 2011, I developed a series of FDEM based hydraulic, thermal, hydrothermal, contact heat transfer, humidity migration-fracture coupling models, and a FDEM based GPU parallel multiphysics fracture analysis software, namely MultiFracS, has been developed. MultiFracS is 2 orders of magnitude faster than the serial version. I have published 46 papers (34 SCI papers) about FDEM as the First author or corresponding author. The total number of citations for these papers is 1614. I am a Guest editor for one SCI journal. I have been invited to give a keynote lecture to introduce FDEM at Hong Kong Polytechnic University.

Abstract:
This report introduces the FDEM GPU parallel multiphysics fracture analysis software MultiFracS, which includes modules such as heat conduction, contact heat transfer, seepage, humidity migration, chemical-fracture coupling models, and rock bolt.

Xiaofeng LI

OpenFDEM: a novel object-oriented FDEM kernel for solving multiscale, multiphase and multiphysics problems in rock engineering

Bio:

Dr. Xiaofeng Li earned his PhD degree from the Institute of Rock and Soil Mechanics, Chinese Academy of Sciences and Monash University in 2019. He is a postdoc in Grasselli's Geomechanics Group at University of Toronto since 2021. His research interests lie in the fields of rock dynamics and computational mechanic sciences with emphasis on the development of the hybrid continuum and discontinuum methods for failure modelling of geomaterials spanning the scale from micro-grain-based heterogeneity (mineral, texture, anisotropy, grain morphology) to macro- in-situ applications (rock faulting, geothermal-induced earthquakes). He is the recipient of the 2021 ROCHA runner-up of the ISRM. He is awarded as future leader of Class 2022 in ARMA. He is the main developer of the open-source continuum-discontinuum code (OpenFDEM), which aims to be a free finite and discrete element kernel with object-oriented architecture for solving multiscale, multiphase and multiphysics (3M) problems that operates on various platforms.

Abstract:

OpenFDEM is a free finite and discrete element solver with object-oriented architecture for solving multiscale, multiphase and Multiphysics (3M) problems that operates on various platforms. The applications are, but not limited to, mechanical, thermal and fluid problem with additional acceleration techniques to boost the calculation speeds. OpenFDEM is a portable kernel, which contains static, nonlinear static and dynamic(explicit) solvers, it has a friendly preprocessing module to generate the mesh and supports import from over 6 formats: .g. .geo, .inp, .msh, .stl, .inp, .msh, .stl, .step, .igs, .dxf, .jpg and .tess. The solver is composed of FEM, DEM, thermal, hydro, phasefield, particulate DEM, CFD and MPM kernels. OpenFDEM supports 26 element types and 17 materials, which can be used for brittle, ductile, phasefield, nonlocal, viscous and fatigue problems. The supporting modules, e.g. documentation, GUI, coupling interface and particle library are also built to extend the application. This talk will give an overview of the development and functionalities of the OpenFDEM.

Zhou (Alex) LEI Algorithm Aspects of the Combined Finite-Discrete Element Method: An Overview	

Bio:

Dr. Zhou Lei is a Research Scientist at Los Alamos National Laboratory (LANL). He started to work at LANL as a postdoc in 2012 and has been a staff member since 2015. For over 18 years, Dr. Lei's research efforts have been focused on Computational Mechanics of Discontinua with an emphasis on the combined Finite-Discrete Element Method (FDEM). He did his PhD with Prof. Antonio Munjiza on the development of 2.5D FDEM solutions for shell fracture. At LANL he has been serving as a main developer of LANL's in-house 2D/3D parallel FDEM code, the Hybrid Optimization Software Suite (HOSS). In addition, Dr. Lei has extensive experience in the development and implementation of material models for rock-like materials within continuum mechanics frameworks.

Abstract:

In this lecture, I will give an overview of the algorithm aspects of the Combined Finite-Discrete Element Method (FDEM). The principle of FDEM as well as some detailed key aspects, such as material deformation, contact detection, contact interaction and continua-discontinua transition, will be briefly discussed. I will also talk about the recent development of FDEM within different coordinate systems and in different dimensions.

Lei SUN

A fully coupled cryogenic thermo-hydro-mechanical (THM) model for frozen medium: theory and implementation in FDEM

Bio:

Dr Sun received his BEng from Sichuan University in 2014 and PhD from Wuhan University in 2020. Now he is working as a postdoctoral fellow in Prof. Giovanni Grasselli's group at the University of Toronto. His research interests lie in the fields of rock mechanics and computational mechanics. Recently, his emphasis is towards developing a robust THMC coupling model based on the combined finite-discrete element method (FDEM).

Abstract:

Extensive thermo-hydro-mechanical (THM) models have been recently developed for various engineering applications (e.g., geothermal energy extraction, radioactive waste storage, and oil/gas exploitation). However, a fully coupled low-temperature THM model, considering the water/ice phase change, is still urgent for geotechnical engineering in cold regions (e.g., periglacial landforms, alpine rockfall, artificial ground freezing, liquefied gas storage), especially with the increased concerns with climate change. The research work presented herein introduces a novel fully coupled low-temperature THM formulation implemented into the combined finite-discrete element method code (FDEM) for multiphysics simulation. Emergent numerical results provide novel insights into the strongly coupled multifield for freezing medium (e.g., heat transfer, water migration, and frost heave deformation), as well as the important phenomena (e.g., latent heat, cryogenic suction, and ice expansion) caused by water/ice phase change.

Quansheng LIU

Large deformation process and combined support methods of soft rock tunnel induced by fragment and swelling under high in-situ stresses: an FDEM modelling

Bio:

Dr. Quansheng Liu is a professor and Yangtze River Scholar of Wuhan University, also a chief scientist of the National Key Basic Research Program of China (973 Program). He is the Dean of School of Civil Engineering, Wuhan University, and the Chairman of the Sub-society for Soft Rock Engineering and Deep Disaster Control, Chinese Society for Rock Mechanics and Engineering. His main interests are deep engineering disaster control (analysis, precaution and control methods for large squeezing deformation disaster, in-situ stress measurement and tunnel deformation monitoring in deep weak surrounding rock mass), interaction mechanism and safety control between tunnel boring machine and deep mixed grounds, and the thermo-hydro-mechanical coupled analysis and modelling for fractured rock mass. He has presided over and participated in many national scientific and engineering projects such as the National 973 Program and Natural Science Foundation of China. He has received 4 National Scientific and Technological Progress Prizes (all second class) and 4 provincial scientific and technology progress prizes (1 special class, 2 first class and 1 second class).

Abstract:

Deep tunnels with high in-situ stress and soft surrounding rock frequently encounter large deformation disasters; however, the catastrophe mechanism and support/reinforcement mechanism are still unclear. In view of the advantages of the combined finite-discrete element method (FDEM) in simulating elastic-plastic continuous deformation, fracturing, contact action between rock fragments and calculation efficiency, an FDEM-based numerical software (WHU-FDEM v1.0) had been developed for the soft rock tunnel large deformation induced by fragment and swelling and its control process. Specifically, a GPU-based parallel computing method was proposed, and the calculation efficiency is improved nearly 100 times compared with the traditional serial computing. The simulation results show that under the high in-situ stress, the surrounding soft rock continues to fracture slowly as the decrease of radial stress and the increase of tangential stress. The deep rock fragments compress the shallow fragments, and the shallow fragments undergo macro overturning movement, resulting in a large number of voids, that is, the surrounding rock experiences a large deformation disaster with fragment and swelling effect. Furthermore, the combined support method of lining, rockbolt and grouting are also investigated, where the lining and rockbolt can be simulated by solid modeling and the grouting can be reflected by repairing the broken joint elements, which effectively control the large deformation of soft surrounding rock.

Giovanni GRASSELLI	

Bio:

Giovanni Grasselli is a Professor and the NSERC/Energi Simulation Industrial Research Chair in Fundamental Petroleum Rock Physics and Rock Mechanics at the University of Toronto. His research focuses on hybrid finite-discrete element (FDEM) numerical technology, experimental visualization techniques, and geomechanics principles applied to the study of tunneling and hydraulic fracturing. He received the prestigious ISRM Rocha Medal (2004) for best thesis worldwide in rock mechanics and supervised two Rocha Medal winners (2015 and 2017). Through the start-up company Geomechanica Inc., the FDEM technology is currently commercialized and translated to engineering practice.