HKSTAM
Hong Kong Society of Theoretical and Applied Mechanics

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Jiangsu Society of Theoretical and Applied Mechanics

香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Proceedings of

The 19th Annual Conference of HKSTAM 2015
The 11th Jiangsu – Hong Kong Forum on Mechanics and Its Application

March 28, 2015

Hong Kong University of Science and Technology, Hong Kong

Editors

Gang WANG and Yi-Kuen LEE

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PREFACE

The 19th Annual Conference of HKSTAM (2015) in conjunction with the 11th Jiangsu – Hong Kong Forum on Mechanics and Its Application is held on March 28, 2015 at Hong Kong University of Science and Technology. This conference is co-organized by the Hong Kong Society of Theoretical and Applied Mechanics (HKSTAM), the Jiangsu Society of Theoretical and Applied Mechanics (JSTAM), and the Hong Kong University of Science and Technology (HKUST). The one-day conference aims to provide a platform for all scientists, engineers, and mathematicians working on mechanics and related areas to share, communicate and exchange ideas, and to enhance co-operations within relevant parties. This proceeding consists of 51 abstracts including 4 Distinguished Lectures by Prof. Tongyi ZHANG from Hong Kong University of Science and Technology, Prof. Jinhao QIU from Nanjing University of Aeronautics and Astronautics, Prof. Wen J. LI from City University of Hong Kong, and Prof. Junhua ZHAO from Jiangnan University. The conference also contains 8 parallel sessions with 47 presentations.

The Society appreciates all the speakers and contributors for their efforts to make this event a successful one. Special thanks go to Ms. Xuan WU of JSTAM, for her great help in making connections with various parties and organizing things in Jiangsu. The Society also wishes to thank the generous support from Institution Members of HKSTAM.

On behalf of and for the Executive Committee.

Dr Gang WANG
Secretary of HKSTAM
Associate Professor
Department of Civil and Environmental Engineering
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The 19th HKSTAM Annual Conference in conjunction with The 11th Jiangsu-HK Forum on Mechanics and Its Application

Conference Program (28 March 2015)

Conference Venue: Institute for Advanced Study (IAS) at Hong Kong University of Science and Technology (HKUST)

March 28, Saturday, Morning (IAS Lecture Theatre, HKUST)

08:30 – 09:00 **[30 mins]**	**Registration and reception [IAS Lobby, HKUST]**
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Distinguished Lecture I

Speaker of Distinguished Lecture

Professor Tong-Yi Zhang
Hong Kong University of Science and Technology

Tong-Yi Zhang, PhD in 1985 in materials physics from University of Science and Technology Beijing, China, is Fang Professor of Engineering and Chair Professor of Mechanical and Aerospace Engineering at Hong Kong University of Science and Technology. He is Associate Editor-in-Chief of Science China: Technological Science and the Fracture and Continuum Mechanics Subject-Editor of Theoretical and Applied Fracture Mechanics; and a vice president of the International Congress on Fracture (ICF) and a vice president of The Far East and Oceanic Fracture Society. He was a recipient of two Second Prizes of State Natural Science Award, China, and the 1988 National Award for Young Scientists, China. He became ICF Fellow in 2013, Fellow of the Hong Kong Academy of Engineering Sciences in 2012, member of Chinese Academy of Sciences in 2011, Senior Research Fellow of Croucher Foundation, Hong Kong, in 2003, Fellow of ASM International, USA, in 2001.

The Surface Eigenstress Model and Size-dependent Young's Modulus and Ultimate Tensile Strength

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The surface eigenstress model was developed to study surface-induced size-dependent Young's modulus and ultimate tensile strength. Surface eigenstress gauges the born surface stress of a nanomaterial that still maintains the dimensions as that without free surfaces. In general, tensile (or compressive) surface eigenstress renders a lager (or smaller) nominal modulus of a thin film or a nanowire and thus results in the thinner-the harder (or softer) elastic behaviour. Nonlinear scaling laws were also developed for the thickness-dependent Young's modulus under tension/compression and bending; and for the size-dependent ultimate biaxial tensile strength of thin films. First-principles calculations and molecular dynamics (MD) simulations verified the theoretical predictions from the surface eigenstress model and put insights into the surface induced strengthening or weakening mechanism.

Acknowledgements
The work was supported by a General Research Fund (622312) from the Hong Kong Research Grants Council.

Distinguished Lecture II

Speaker of Distinguished Lecture

Professor Jinhao Qiu
State Key Laboratory of Mechanics and Control of Mechanical Systems
Nanjing University of Aeronautics and Astronautics

Professor Jinhao Qiu is Deputy Director, State Key Laboratory of Mechanics and Control of Mechanical Systems. He received the Bachelor and Master degrees in mechanical engineering from Nanjing University of Aeronautics and Astronautics, China, in 1983 and 1986 respectively, the PhD degree in mechanical engineering from Tohoku University, Japan in 1996. He was a research associate from 1986 to 1989 and lecturer 1990 to 1991 at Department of Mechanical Engineering, Nanjing University of Aeronautics and Astronautics. He was a faculty member at the Institute of Fluid Science, Tohoku University from 1992 to 2006, where he was a research associate from 1992 to 1998, an assistant professor 1998 to 2000, an associate professor from 2000 to 2004 and a professor from 2004 to 2006. Since March, 2006, he is a Changjiang Chair Professor at the Nanjing University of Aeronautics and Astronautics. In 2011, he was selected to “The Recruitment Program of Global Experts”. His main research interest is smart materials and structural systems, including development of piezoelectric materials and devices, vibration and noise control, structural health monitoring, and active flow control for aerospace applications. He has published 240 journal papers, 12 review papers, and more than 200 conference papers. He has also received 8 awards, including The 2002 Annual Dynamics, Measurement and Control Awards for Pioneering Achievements in the research of smart materials and structural systems from The Japan Society of Mechanical Engineers. He is the associate editor of Journal of Intelligent Material Systems and Structure, member of editorial board of International Journal of Applied Electromagnetics and Mechanics and other four journals. He became ASME Fellow in 2014.

Lamb Waves Based Detection of Fatigue Damage Accumulation in Composites

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Stress induced fatigue damage can lead to the degradation of material properties and the unsafety of composites structures, which thus makes it essential to conduct non-destructive evaluation of the fatigue damage in such structures. In this paper, a laser-generation based imaging (LGBI) system was used to study the relationship between three parameters and the fatigue loading cycles of composites. The three parameters are the amplitude of Lamb waves, the phase velocities and the elastic moduli of the fatigue test samples along the loading direction, respectively. The amplitude and phase velocities of Lamb waves were obtained with the position-time digrams, while the elastic moduli was reconstructed based on the Lamb waves velocities.

The relationship between each parameter and the fatigue loading cycles is indicated in the following figure. It was observed that the amplitude of the received signal is much more sensitive to the presence of fatigue damage comparing with the wave speed or the elastic moduli.

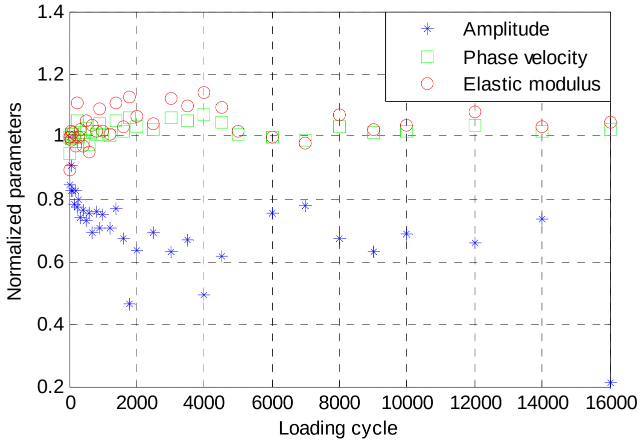

Figure 1. The relationships between the three normalized parameters and the fatigue loading cycles of composites.

Acknowledgements

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Distinguished Lecture III

Speaker of Distinguished Lecture

Professor Wen J. Li
City University of Hong Kong

Wen J. Li received his BS and MS degrees (in aerospace engineering) from the Univ. of Southern California in 1987 and 1989, respectively, and his Ph.D. degree from the Univ. of California, Los Angeles, in 1997. He is currently Chair Professor of Biomedical Engineering in the Department of Mechanical and Biomedical Engineering of the City University of Hong Kong (CityU). Prior to joining CityU, he was with The Chinese University of Hong Kong (from 1997-2011), where he headed the Centre for Micro and Nano Systems. He held R&D positions at the NASA Jet Propulsion Laboratory (Pasadena, CA), The Aerospace Corporation (El Segundo, CA), and Silicon Microstructures, Inc. (Fremont, CA), before moving to Hong Kong in 1997. His research group has published over 300 technical papers since 1998 and has received numerous best conference paper awards from prestigious conferences such as IEEE-ICRA, IEEE/ASME AIM, IEEE-ROBIO, and IEEE-NANO in the past 15 years. Dr. Li served as the Editor-in-Chief of the *IEEE Nanotechnology Magazine* from 2007 to 2013, and was elected to serve as the President-Elect of the IEEE Nanotechnology Council in 2015, then as its President in 2016 and 2017. Dr. Li has co-founded 3 startup companies (in Hong Kong and China) which are currently commercializing MEMS and nano-sensor related products worldwide. He was elected IEEE Fellow in 2010 and ASME Fellow in 2011. He was honored as a Distinguished Overseas Scholar of the Chinese Academy of Sciences (100 Talents Plan), and currently holds several honorary/affiliated academic appointments, including those from the Shenyang Inst. of Automation (CAS), Peking Univ., Huazhong Univ. of Science and Technology, and Shenzhen Institute of Robotics.

Rapid Determination of Single Cancer Cell Mass and State by Opto-electrokinetics

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***O**pto-**e**lectro**k**inetics* (OEK) has found many applications in biological and micro-/nano-scale manipulation, separation, and assembly in the past decade. In this lecture, OEK is envisioned as a fundamental technology that uses localized and real-time-reconfigurable (programmable) electric fields to enable rapid manipulation and assembly of entities ranging from molecular to micron-scale dimensions in fluidic media. We will demonstrate several applications related to cancer cell research using OEK, including *1*) rapid and non-UV-based patterning of hydrogels to study the effects of mechanical stress on breast cancer cell growth; *2*) inducing *self-rotation* of cells with rotational characteristics that are uniquely related to the electrical and mechanical properties of each type of cell; 3) differentiation of cells by their transient acceleration response under specific OEK force fields; 4) determination of single cancer cell mass, density, and cycling state using pulsed OEK force. We will also show the multiplicity of OEK applications by demonstrating other non-biological related results such as in-situ fabrication of microelectrodes, nanowires and polymer nanolenses using programmable electric fields in microfluidic media.

Distinguished Lecture IV

Speaker of Distinguished Lecture

Professor Junhua Zhao
Jiangnan University

Dr. Junhua Zhao is a full professor at School of Mechanical Engineering, Jiangnan University (Wuxi, Jiangsu Province). In 1997-2001, Dr Zhao studied Civil Engineering in Wuhan Institute of Technology and obtained his bachelor's degree. He received his first Ph.D. degree (majored in Engineering Mechanics) at Nanjing University of Aeronautics and Astronautics in 2008. From 2008 to 2011, he was a postdoctoral research fellow in Norwegian University of Science and Technology. From 2011-2014, he worked in Bauhaus-University Weimar of Germany and received his second Ph.D. degree in Micro/nano Mechanics. In 2015, he was selected to the 1000 Youth Talent Program in China.

His research interests focus on: (1) fatigue and fracture simulations of complex structures; (2) Multi-scale modeling of polymers, carbon nanotubes, and composite materials. He published more than 40 papers in prestigious journals. He is an invited reviewer for more than 10 international journals, including Physical Chemistry Chemical Physics, Journal of Applied Physics, Engineering Fracture Mechanics, Computational Materials Science, Acta Mechanica, International of Damage Mechanics, and Materials Science and Engineering C.

The Interface Strength and Debonding for Composite Structures: Review and Recent Developments

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The interface behavior between coated films, coated spheres and carbon nanotube (CNT)-reinforced composites governs their mechanical properties due to the large interface area per unit volume at these structures. Predicting the interface strength and debonding of these structures has been a challenge for decades. In this paper, a review of interface models is presented. The focus of this review is on cohesive zone models (CZMs) developed from interatomic potentials which are needed to study the interface debonding of large structures. Such models are important for the design of new microcomposites and microelectromechanical systems.

Acknowledgements

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Technical Papers

in situ Nano-Fatigue Characterizations of 1-D Nanostructures

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In this presentation, we will focus on the important issue for the structural reliability of various 1-D nanostructures under cyclic loading (mechanical, thermal, electromechanical…), because any fascinating engineering applications based on these nanosized 1-D building blocks will be ultimately limited by their fatigue behaviour. We will firstly present our successful development on the *in situ* nanomechanical characterization techniques for nanowires with a wide range of diameters, ranging from hundreds of nanowires down to sub-10nm level. Then we will report our experiment results on testing cyclic behaviour of nanotwinned copper pillars inside a high-resolution TEM, as well as the preliminary results on the fatigue properties of metallic nanowires and silicon nanowires. Lastly, we will demonstrate our on-going development of a high-cyclic nano-fatigue testing platform based on "digital micromirror device" (DMD).

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The authors wish to thank the funding support from Hong Kong RGC under the ECS grant #138813 and CityU start-up grant #9610288.

Atomistic deformation mechanisms in copper nanospheres

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Nanospheres/Nanoparticles play important roles in many fields such as fuel cells, energetic materials and high performance catalyst and so on. Understanding their mechanical behaviours is critical for the applications. Atomistic simulations are performed to illuminate the anisotropic deformation in the compression of metallic nanospheres. In elastic regime, the compression load-depth behaviors can be fitted well by the classical Hertzian prediction, while the reduced moduli vary in different compression directions. In initial plastic deformation, surface step plays an import role in dislocation nucleation, and characteristic structures such as pyramid hillocks or prismatic dislocations are observed when compression direction varies. In severe deformation, deformation twinning, cross slip and glide of extended dislocations dominate the plastic behaviors in different directions. The corresponding deformation mechanisms transfer from gliding of jogged dislocations for <111> compression and extended dislocations for <110> compression, to deformation twin for <100> and <112> compression. However, by introducing defects such as twins into the pristine structures, the mechanical properties of nanospheres are greatly enhanced. We also perform simulations to investigate the compression response and atomistic deformation mechanisms of twinned nanospheres. The relationship between load and compression depth is calculated for various twin spacing and loading directions. Then, the overall elastic properties and the underlying plastic deformation mechanisms are illuminated. Twin boundaries (TBs) act as obstacles to dislocation motion and lead to strengthening. As the loading direction varies with respect to twin planes, the plastic deformation transfers from dislocations intersecting with TBs, slipping parallel to TBs, and then to being restrained by TBs. The strengthening of TBs depends strongly on the twin spacing. Moreover, the enhancement of TBs increases evidently as the twin spacing decreasing, obtaining its maximum at a critical twin spacing, and then declines. Present studies are helpful to measure the mechanical properties of metallic nanospheres and design nanoparticle-based devices.

Acknowledgements

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Indentation Size Effect of Ceramic Particle Reinforced Polymeric Nanocomposites

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Ceramic particle reinforced polymeric composites are widely adopted for versatile applications. In the recent decades, advancing of micro and nano technology stimulates the need to characterize, analyse and study the size effects on mechanical property of nanocomposites. In our study, nanocomposites were fabricated with resin based polymer reinforced with ceramic nanoparticles. Size dependent mechanical properties and deformation mechanism were studied by utilizing multi-scale indentation experiments. The relationships between hardness and Young's modulus versus indentation depth were investigated. The experimental results demonstrated the presence of size effects in nano composites. Furthermore, the effects of filler contents and their influence upon size effects in polymer nanocomposites were also discussed. All the works are in the hope of providing guidance for the design of nanocomposites.

Acknowledgements
This work is supported by Hong Kong ITC grant ITS/350/12, Hong Kong RGC Early Career Scheme grant 138713 and City University of Hong Kong Start-up grant 7200274.

Thickness-dependent Fracture of Amorphous Carbon Coating on SnO_2 Nanowire Electrodes

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Carbon-coated SnO_2 nanowires (NWs) were fabricated and applied as electrode to study the lithiation process using *in situ* transmission electron microscopy (TEM). A critical coating thickness (~9 nm) was found, above which the carbon coating is able to constrain the lithiation-induced expansion of SnO_2 core without failure. Theoretical modeling and numerical simulation were performed and revealed that such thickness-dependent fracture can be attributed to the thickness-dependent maximum stress developed in the carbon coating during the lithiation of SnO_2 core. Our work provides direct evidence of the mechanical robustness of thick carbon coating and offers a minimum thickness of carbon coating for constraining the deformation of anode materials with large lithiation-induced volume change.

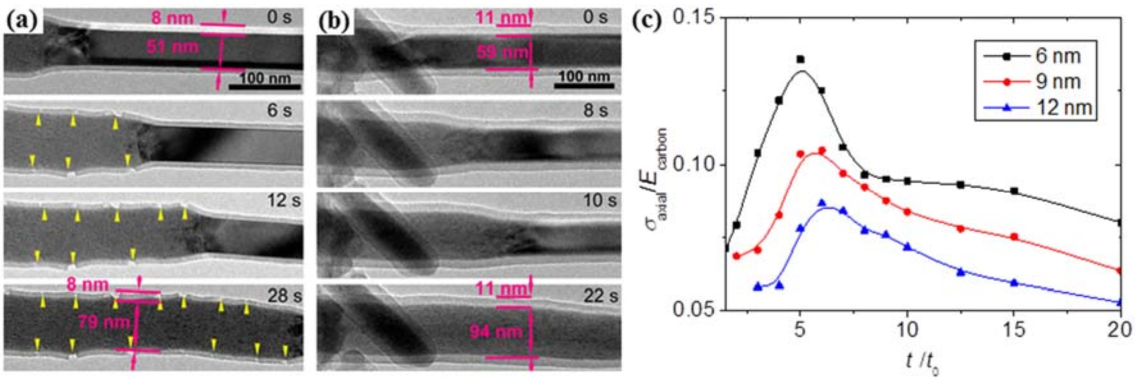

Figure 1. The TEM images of morphology evolution and crack occurrence (marked by yellow arrows) during lithiation of SnO_2/C NW with different coating thicknesses: (a) 8 nm and (b) 11 nm; (c) Evolution of the maximum stress in carbon coatings of different thicknesses.

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Room-Temperature Super Elasticity of Single Crystalline Silicon Nanowires

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Due to size effect, brittle materials such as silicon (Si) tend to become flexible at nanoscale. In this work, we further show that, by uniaxial straining, VLS-grown single crystalline Si nanowires (with diameters less than 100 nm) demonstrated extraordinary elastic properties, with elastic strain generally larger than 10%, making them excellent candidate for flexible electronics, epidermal electronics, and many nano-bio interface applications. The ability to achieve such "ultra-strength" (approaching to theoretical strength due to the large elastic strain) was believed to be associated with various nanoscale size effects, and we also ruled out the electron beam effect, a common challenge for many existing nanoscale property characterizations, by performing additional measurements under optical microscope in ambient environment. This result may indicate that other semiconductor nanowires could have similar unusual large lattice strains, making their band-gap structures tunable for promising elastic strain engineering (ESE) applications.

Acknowledgements

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Unzipping of Twin Lamella in Nanotwinned Nickel Nanowires

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Twin structures in bulk metal crystals strongly influence their mechanical behaviour, which could be also applicable for nanomaterials. In the present study, we report that nickel nanowires with unusual parallel nanotwinned structures ("twin lamella") could demonstrate interesting "unzipping" phenomenon for their twin lamella during mechanical deformation. By using *in situ* mechanical loading with high-resolution transmission electron microscope (HRTEM), it is showed that twin spacing gradually increased along the nanowire axis via a layer-by-layer twin boundary migration process. We propose the slip of partial dislocation shall be one of the underlying mechanisms, which has been further confirmed by molecular dynamics (MD) simulation. On the twin plane, we find a four-step-process of dislocation, namely, dislocation loop initiation, expansion, partially annihilation and further slip with increased deformation. Meanwhile, dislocations are also nucleated at the surface of the deformed nanowire, with the slip of such dislocations leading to formation and growth of stacking fault. These results may help understand the unique deformation mechanism of metallic nanowires with nanotwinned structures.

Acknowledgements

The authors wish to thank the funding support from Hong Kong RGC under the ECS project #138813 and National Science Foundation of China (NSFC) under the grant #51301147. B. Wang also gratefully thanks the CityU International-Transition Team scheme (ITT-GTA) postdoctoral fellowship.

Numerical Comparison of Two Solvers on The Effect of Hydrogen Addition on Laminar Premixed Counter-flow CH_4-air Flames

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A Computational Fluid Dynamics solver OpenFOAM (Weller et al., 1998) and a benchmark solver based on the hybrid Newton method, CANTERA (Goodwin, 2003) are compared on a CH_4-H_2-air premixed flame. Full chemistry is used for both codes but a multispecies model is only implemented in CANTERA. Computations are realized at room temperature and atmospheric pressure on a counterflow planar flame model to examine the effects of stretch rate on the combustion features. Three different global equivalence ratios of 0.7, 1.0 and 1.2 are investigated with different amounts of hydrogen fraction added, up to 50% in the mixture. Influence of hydrogen enrichment on laminar flame speed, temperature of flame, flame stability and NO_x emission is studied. Results show that laminar burning velocities and flame temperatures increase against the hydrogen volume fraction and this effect is more remarkable at a large stretch rate, when the Markstein length decreases. However, such change of behavior depends on the equivalence ratio. Damkohler number increases with the fraction of hydrogen and faster for richer flames. Concerning NO_x emissions, peak of emissions in the counteflow are investigated. NO production declines with hydrogen addition and with the increase of the stretch rate. NO_2 emissions increase with the equivalence ratio, and generally decrease when the stretch rate is higher and/or the fraction of hydrogen grows.

From a comparative point of view between the 2 solvers, OpenFOAM matches the results of CANTERA for the different parameters studied when the flame is stoichiometric at $\phi = 1.0$ and rich at $\phi = 1.2$. However, for the lean case when $\phi = 0.7$, more discrepancies between the codes are found, especially at high stretch rate close to extinction.

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Large Eddy Simulation of a Swirl-stabilized Pilot Combustor from Conventional to Flameless Mode

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Lean premixed combustion (LPM) is one of the most promising technologies that aims to take advantage of the fact that combustion processes operating under fuel lean conditions can have very low emissions and very high efficiency. One of the common methods to increase energy efficiency in almost all combustion systems including LPM is increasing the mixture temperature using recovered exhaust heat directly, such as e.g. preheat-dilution of reactants with high temperature products, or indirectly suing recoupaerators. Employing these methods in LPM combustion not only increases the efficiency of the system but also improves combustion stability and flammability limits. Despite its benefits, increasing the temperature of the reactants above a certain level may give rise to thermal NO_x formation in conventional premixed combustion, thereby limiting the potential of this method in producing less NO_x. The current study is to investigate the flame and flow structure of a swirl-stabilized pilot combustor in conventional high temperature air combustion (HiTAC) and flameless mode using finite rate chemistry combustion model and large eddy simulation (LES). To achieve the second mode the mixture temperature is increased from room temperature to slightly higher than self-ignition temperature. Equivalence ratio of the highly preheated lean mixture is thus decreased to 0.3 to attain the flameless mode.

Results show that by moving towards the HiTAC mode solely by increasing the preheating level, (i) the combustor is more prone to formation of thermal NO_x due to higher temperature of the products (ii) the flame becomes shorter and thinner due modification of laminar flame speed and (iii) the turbulent kinetic energy of incoming flow grows. Approaching the flameless mode, however, leaning the highly preheated mixture leads to (i) an almost thermal NO_x free combustion (ii) thicker and longer flame without any significant modification of the upstream turbulence level.

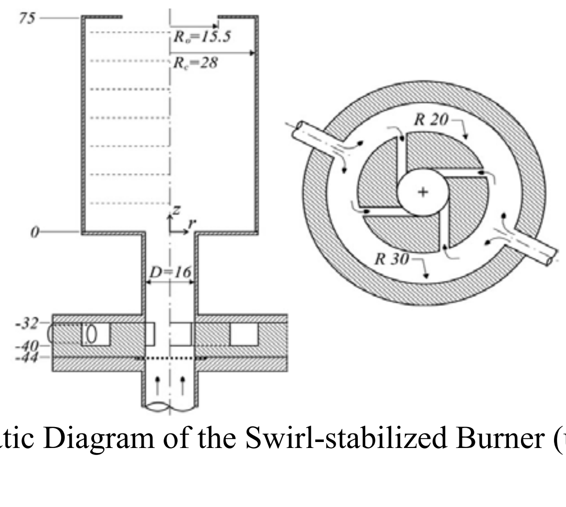

Fig. Schematic Diagram of the Swirl-stabilized Burner (units in mm)

Numerical Study of Wake Flow Characteristics of a Five-straight-bladed Vertical Axis wind Turbine Based on Computational Fluid Dynamics

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The wake flows of vertical axis wind turbine (VAWT) experience drastic evolutions, which poses a great threat to the downstream wind turbines. The optimal placement of multiple wind turbines in a given area requires in-depth understanding of wake aerodynamics (Tescione et al., 2014). This work presents a numerical study on the velocities and vortices in the wake of a five-straight-bladed VAWT based on computational fluid dynamics (CFD). The wind tunnel testing results were employed to validate the three-dimensional CFD model. A good agreement between the CFD predictions and the experiments was achieved. The analysis results show that the wake of VAWT has major shift towards the windward side while the wake asymmetry further grows in the downstream direction. Furthermore, both the vortices shed from blade span and the vortices casted from the blade tips contribute to the development of wake asymmetry. A fast wake recovery mechanism of VAWT is verified and thereby detailed by the CFD analyses.

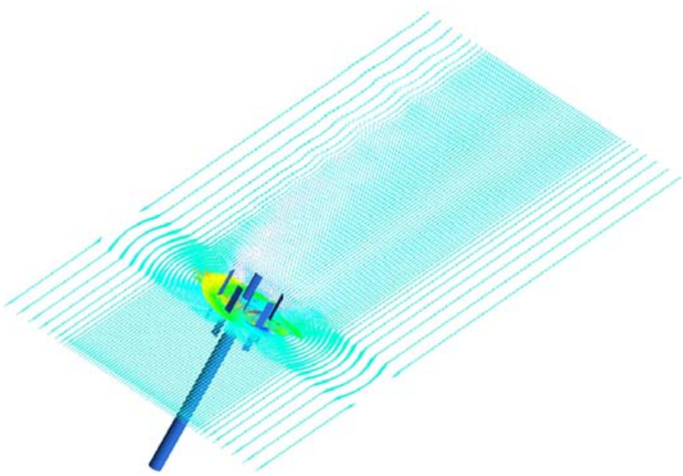

Figure 1. Velocity vector plot at blade mid span.

Acknowledgements

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A Monte Carlo Based Method Simulating Both Particle and Wave Behaviours of Phonon Transport

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It is a challenging task to understand and model the submicron heat transport in semiconductors, especially in nanoscale superlattices and composites. Currently, heat transport is either modeled at the atomic level using, for example, molecular dynamics or lattice dynamics, which has a limitation on the problem size that can be handled; or investigated through transport of phonons, which are treated as classical particles governed by Boltzmann transport equation (BTE). In the pure particle picture of phonons, the phase information carried by phonon waves is ignored. Hence such an approach is only valid in the incoherent regime. However, the coherent phonon transport, due to the interference of phonons scattered from the interfaces, is known to exist and has been demonstrated experimentally [1]. Over a considerable range, both coherent and incoherent phonon transport are likely to be important, and hence a mesoscopic method that can simulate both two effects would be highly desirable.

Inspired by the work in which the motion of wave packets was simulated using a particle approach and the interference effect was considered by superposing the amplitudes of two phonons based on phase information [2], a new Monte Carlo (MC) method has been developed to simulate both particle and wave behaviours of phonons. In this approach, phonon is still modeled as a particle, but carries its phase information. When a phonon hits an interface and coherent interference occurs, it preserves its phase information. When the phonon undergoes scattering process as it does in the conventional MC, the phase information is destroyed and assigned to a random value. An interface simulation model that allows both coherent phonon transport and anharmonic scattering has been constructed to facilitate the simulation of phonon transport across an interface. Preliminary studies have been conducted in the superlattice structure with identical materials separated by artificial interfaces using our developed method. It has been shown that in the diffusion limit, the new method and the conventional MC produce the same temperature and heat flux as expected, whilst in the wave regime, the results obtained from the two methods are vastly different with those obtained from our new method being more closed to the experimentally observed trend, that is, the thermal conductivity of superlattice increases with the increased number of periods [1].

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A Robust Simulation Method for Curvature Driven Flows

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The level set method is a popular interface tracking method that has been used widely in many applications including two-phase flow simulation. Although the level set method can handle topological changes naturally, its performance in simulating curvature driven flows highly depends on how accurate the interface curvature can be simulated, particularly in cases when topological change happens at interfaces that are close by, e.g. droplet collision phenomena. Based on the high-order accurate approach developed by Saye for computing the minimum distance to implicitly defined surfaces, we have developed a new accurate method that can handle general interface configurations including multiple interfaces that are close by. This new approach can be extended easily to 3D problems and is suitable for any kind of meshes: structured and unstructured meshes.

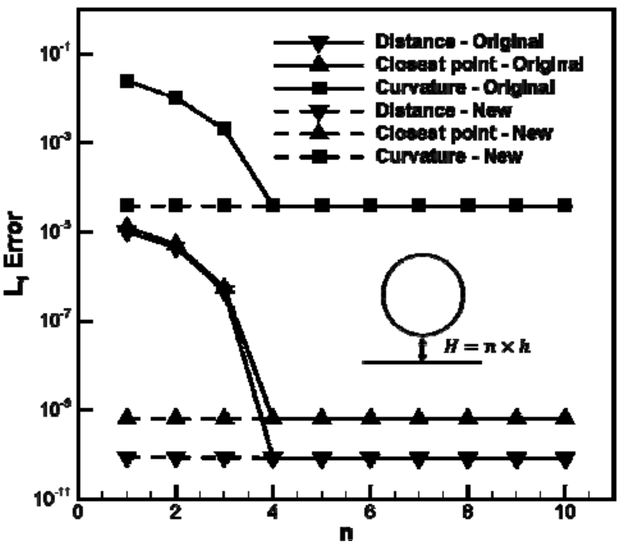

Figure 1. Comparison of L_1 errors for distance, closest point and curvature.
Solid line: original method. Dashed line: robust method.

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On the Validity of the Young-Laplace Equation for the Fluid Infiltration in Hydrophobic Nanochannels

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We investigate the validity of the Young-Laplace equation by studying water infiltration into hydrophobic nanochannels through molecular dynamics simulations. At the nanoscale, it is found that the energy barrier at the channel entrance significantly raises the infiltration pressure and the classic Young-Laplace equation underestimates the infiltration pressure. As the channel surface is tuned from superhydrophobic to hydrophobic, the infiltration pressure is greatly reduced due to the decrease of capillary pressure (Young-Laplace equation) caused by the contact angle change, while the contribution of the entrance energy barrier to the infiltration pressure increases from 25% to 60%.

Acknowledgments

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The Study of Cancer-cell Capturing in Microfiltration Chips under Different Capillary Numbers

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We present a systematic study of the Capillary number (*Ca*) effect on the cancer-cell capturing in microfiltration devices, in which the capture efficiency (η_c) of cell as the result of the competition between the viscous force from flow and cell's membrane tension has been both experimentally and theoretically explored. A "Phase Diagram" for the η_c as a function of normalized cell diameter d^* and *Ca* has been generated and verified to be reliable. A 2-DOF model for the deformation and capturing of single cell (simplified as mass-spring-damper system) on a pore was also proposed showing consistent with the experimental results by identifying a critical value of *Ca* for enhancing the capturing of cancer cells. This phase diagram will be useful in the design of the next-generation microfiltration devices for isolating Circulating Tumor Cells (CTCs).

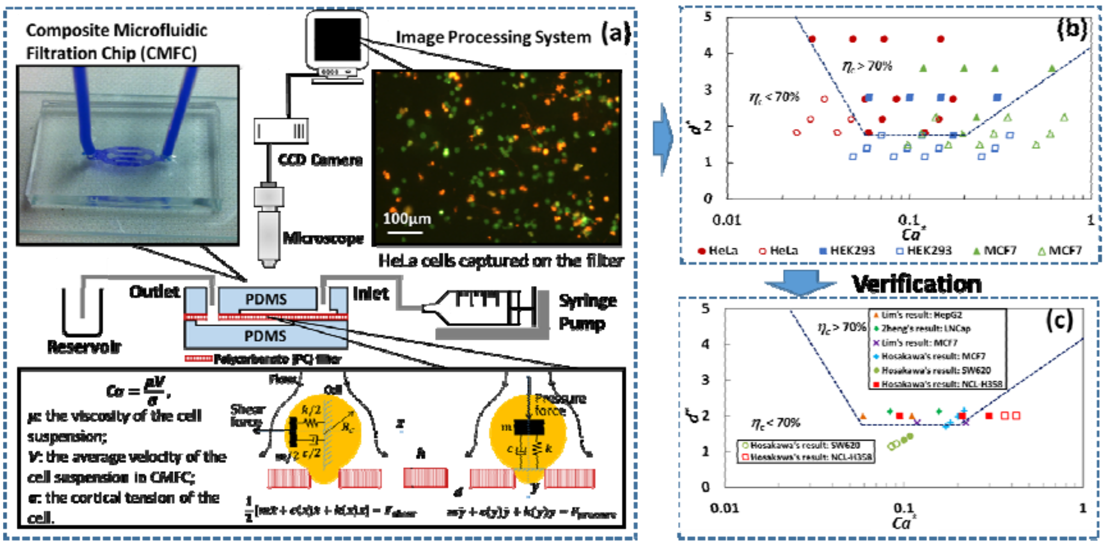

Figure 1. Systematic study of the Capillary number (*Ca*) effect on the cancer-cell capturing in microfiltration chips. (a) the modelling and experimental setup for studying the capturing of cancer cells in microfiltration chips under different *Ca*; (b) the 'Phase Diagram' of the η_c for 3 cancer cell lines (70% as the cut-off point) as a function of the normalized cell size ($d^*=d_c/d_p$, in which d_c is the cell diameter and d_p is the filtering-pore size) and the square root of *Ca*, Ca^*=sqrt(*Ca*); (c) verification of the 'Phase Diagram' by including in the experiment results from various microfiltration systems for CTCs in the literatures.

Acknowledgements

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Resistivity Profile of Single Pore during Electroporation

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The cell membrane is a selective barrier for extra cell compounds. One method to deliver these compounds into the cell is to apply intensified electric field on the cell membrane to induce temporarily nanopores on lipid bilayer [1]. As a result of the applied voltage on the cell membrane the increase in total energy of membrane results in faster lipid fluctuations. Once the energy across the lipid bilayer increases a small defect is induced on lipid bilayer. The defect keeps expanding to generate a hydrophobic pore on the lipid membrane. The induced hydrophobic pore is too small that the ions can not pass through it. At this stage still the resistivity of the electropore is too high. Once the radius of the expanded electropore reaches a specific value, 3-5 Å, the hydrophobicity of pore changes and the hydrophilic pore generated [2]. At this stage the ions can pass through the pore and the transmembrane voltage starts decreasing. After Breakdown stage the transportation of ions and media molecules through the electropore results in sharp decrease in resistivity of the electropore. At this stage the electropore size is large enough that larger compounds such as Propidium Iodide (PI) dye pass through it.

$$R_p = \rho\left(1/2r_p + h/\pi r_p^2\right)$$

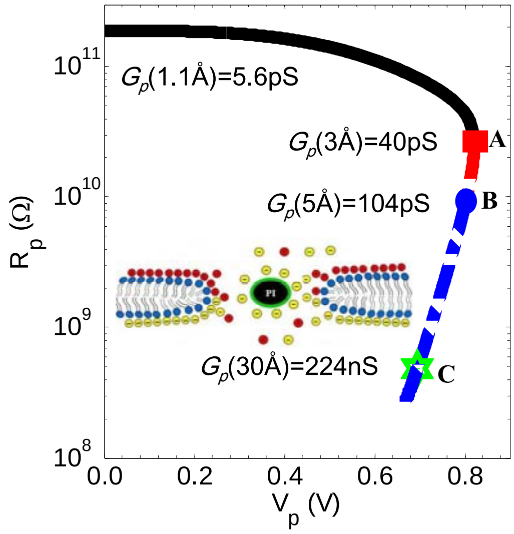

Figure 1. .Resistivity of single pore as a function of voltage on lipid bilayer of cell membrane during EP.

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Poro-Visco-Hyperelastic Modelling of Hydrogel Composites

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Hydrogel composites are cross-linked polymeric networks filled with particles and high water content. They are widely used as tissue/cell culture scaffolds, biomedical adhesives and healthcare products because of their biocompatibility and tuneable properties. As the performance of hydrogel composites significantly relies on their mechanical properties, it is required to understand and to model their mechanical behaviours. Hydrogel composites are believed to have hyperelasticity, viscoelasticity and poroelasticity. Obviously, it's difficult to capture all the three within one mechanical model. In recent years, researchers proposed hybrid models for visco-hyperelasticity for biological tissues [Lucas *et al*., 2008] and poro-viscoelasticity for hydrogel [Wang *et al*., 2014]. As an attempt to provide a unified model for hydrogel composites, a poro-visco-hyperelastic model was proposed in this study. This poro-visco-hyperelastic model was based on Quasi-Linear Viscoelastic (QLV) model proposed by Fung [Fung, 1981]. Considering the similarity of the phenomena of poroelasticity and viscoelasticity, a 3-term Prony series was adopted as the reduction part in QLV to model the viscoelasticity and the poroelasticity of hydrogel composites. Mooney-Rivlin model was selected as the hyperelastic part in QLV. To evaluate this model, 6 types of Poly(ethylene glycol) diacrylate (PEGDA)-Silica hydrogel composites with different concentrations of polymer matrix and silica nanoparticles were fabricated and tested under uniaxial compressive load with 4 different strain rates. The results demonstrated that the model agrees with the experimental data well. Besides, this model revealed the influence of the concentration of polymer matrix and silica particles on the stresses relaxed by viscoelasticity and poroelasticity. Therefore, the poro-visco-hyperelastic model proposed in this study could not only model the hyperelasticity, viscoelasticity and poroelasticity, but also reveal basic mechanisms and provide deeper understanding of hydrogel composites.

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A Novel Technique of Probing Coupled Cell Adhesion and Mechanical Deformation by Optical Tweezers

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By combing optical trapping with fluorescence imaging, the adhesion and deformation characteristics of non-adherent cells were probed on single cell level. We found that, after 24 hours of co-culturing, stable attachment between suspension K562 cells and polystyrene beads coated with fibronectin, collagen I, or G-actin can all be formed with an adhesion energy density in the range of $\sim 1-3\times 10^{-2}$ mJ/m^2, which is order of magnitude lower than the reported values for several adherent cells. In addition, it was also observed that the formation of a stronger adhesion is accompanied with the appearance of a denser actin cell cortex, especially in the region close to the cell-bead interface, resulting in a significant increase in the apparent modulus of the cell. Findings here could be important for our understanding of why the aggregation of circulating cells, like that in leukostasis, takes place in vivo as well as how such cell clusters behave. The method proposed can also be useful in investigating adhesion and related phenomena for other cell types in the future.

Shape Deformation of the Nuclear Envelope during Cell Division

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Lower eukaryotes, such as the fission yeast (Schizosaccharomyces pombe), undergo closed mitosis during which the nuclear envelope (NE) stays intact but changes shape dramatically, usually from a sphere to an ellipsoid and then to a dumbbell for wild-type cells. In comparison, the NE in gene-deletion mutants of the yeast can undergo asymmetric division which often involves tethering or budding of the nuclear membrane. Although it is widely known that closed mitosis is driven by the pushing forces generated among microtubules (MTs), connecting two spindle pole bodies (SPBs) residing at each end of the cell, and associated protein motors, the fundamental question of why and how distinct shape transformations of the NE take place is still poorly understood.

Here we report a combined experimental and theoretical study to address this important issue. Specifically, shape evolution of the cell nuclei in the wild-type and different mutants, with known gene defects, of fission yeast was closely monitored with live-cell imaging at high temporal resolution. Interestingly, it was found that structural deficiencies in one or both SPBs will cause the improper assembly and anchoring of mitotic spindle microtubules and ultimately lead to the formation of a single or multiple tethers. On the theoretical side, a physical model was also developed to predict the nuclear shape during mitosis based on energetic considerations. Our model suggests that, in addition to the bending rigidity and surface energy of the nuclear membrane, the spatial distribution of internally generated forces on the NE plays a key role in its shape transformation, with forces localized on both poles of the cell resulting in membrane tethering while a load distribution over a broad area typically leading to the formation of two equal-sized spherical daughter nuclei. These results provide physical explanations on how complex shapes of the nuclear envelope are developed during cell division as well as elucidate their correlations with structural alterations in the nuclear-cytoskeleton, as indicated in our experiments.

Mechanical Behaviour of Filamentous Networks Governed by the Physical Properties of the Cross-linking Molecules

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It is well-known that the mechanical response of live cells is largely determined by its cytoskeleton, a network consisting of different bio-filaments such as F-actin and microtubules that are interconnected and bundled together by a variety of crosslinking proteins. Although accumulating evidence has shown that the physical properties of cross-linkers can significantly influence the bulk behavior of such biopolymer networks, the underlying mechanisms remain unclear and a quantitative mapping between the two is still lacking.

Here we present a computational study to address this important issue. Specifically, a combined finite element – Langevin dynamics (FEM-LD) approach was employed to examine the mechanical behavior of randomly cross-linked F-actin network where, besides bending and stretching, thermal fluctuations of individual filament have also been taken into account. The cross-linker is modeled as a combination of linear and rotational springs that resists both separation and relative rotation between two filaments and disengages from the F-actin once the strain energy stored inside reaches a critical level. It was found that networks with compliant cross-linkers, such as α-actinin, exhibit low bulk moduli with no apparent strain-hardening because most of the imposed strain was actually absorbed by those highly-deformable crosslinking molecules. In addition, we showed that increasing the rotational spring stiffness of cross-linkers will lead to a more homogeneous load distribution, as well as deformation, within the network. Interestingly, stress-strain curves obtained from our simulations are decorated with sudden load drops, corresponding to the breakage of individual crosslink points, which demonstrates that deformation will generally not progress in a smooth fashion. Finally, the influence of entropy was found to be important only when the strain level is low (less than ~1%) while the network response is dominated by elasticity at large strains. Nevertheless, thermal fluctuations of F-actin seem to always advance the onset of crosslink breakage. Connections between our results and various experimental findings will also be discussed.

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中医经络与振动模态

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经络理论是中医学的基本组成和核心内容之一，是中医针灸学的理论基础。可经络的客观基础是什么这一关键问题却长期悬而没决，这对从机理上深入理解经络的作用和功能是一大障碍，这也是目前对中医理论持怀疑态度人士的理由之一。在大量经络学的研究基础上，综合多项实验结果，借鉴振动理论中的模态概念，本文提出经络是人体内具有模态特性的系统新的假说。该假说可以从科学角度解决经络的实质和物质基础是什么这一关键性问题，并从振动模态的运动同步性、模态间能量独立性、窄带滤波性这三个特性方面阐述经络在传递人体信息中的作用。同时指出，人体的模态是有机生物上的模态，在机理上与非生物结构的振动模态存在差异。另外从发现方法上也比较了中医经络的发现与现代模态测试方法的类似性。新的经络假说可能给经络理论的科学化研究提供一种新的思路.

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Effect of Endothelial Cell Morphology on Hemodynamic Forces in Blood Transport

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Many experimental and computational studies have implicated the local hemodynamics in blood vessels, particularly the shear stresses on the endothelial cells (ECs), in the pathology of atherosclerosis and other cardiovascular diseases. EC morphology and many of the biomolecular processes they regulate are shear-dependent; however, most blood transport simulations do not account for EC shape when analyzing shear stresses and instead assume a smooth wall. In order to evaluate the effect of EC morphology, 3D models of straight and curved vessels with either smooth walls, sheared ECs, or unsheared ECs are constructed and flow transport inside these vessels is simulated. A kernel independent fast multipole BEM was developed and used to simulate Stokes flow within the vessels, and shear stresses along the vessel wall were evaluated and compared. It was found that for both the straight and curved vessel cases, the models with ECs resulted in a greater maximum wall shear stress than the models without ECs. The percent difference was larger for vessels with unsheared ECs compared to with sheared cells, and the influence of the ECs on shear stresses was greater along the outer curvature of the curved vessel compared to the inner curvature or straight vessel. This study used an idealized arrangement of ECs and simple vessel shapes, but nonetheless, we are able to present that endothelial cell morphology, or lack thereof, can greatly affect the hemodynamics simulation results.

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c-axis Preferential Orientation of Hydroxyapatite Accounts for the High Wear Resistance of the Black Carp(mylopharyngodon Piceus) Teeth

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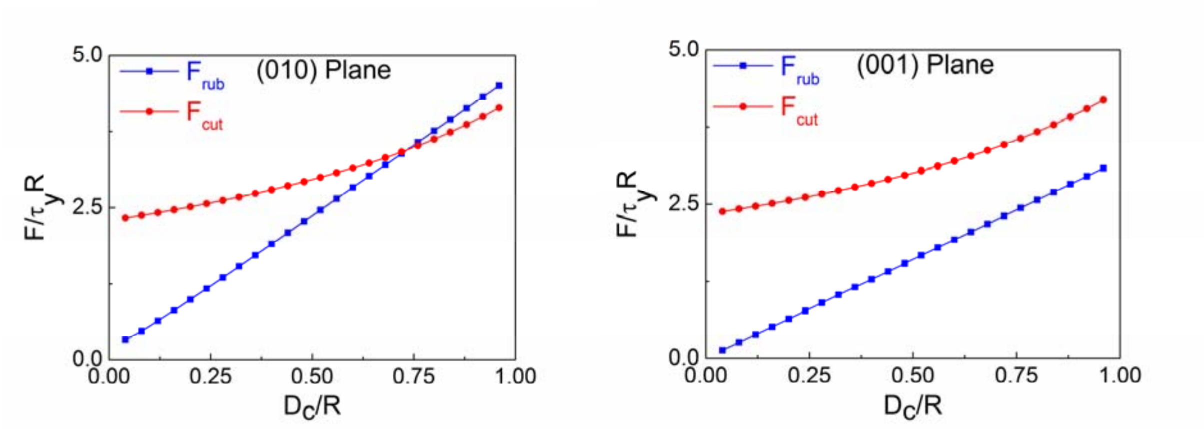
Enameloid, the outmost layer of teeth exhibits high wear resistance. In this research, our attention is focused on the enameloid of the black carp (Mylopharyngodon piceus) teeth, which remain functional after frequent mechanical contacts with the hard mollusk shells. By nanoscratching test conducted on different facets of the enameloid, we find that the occlusal surface exhibits much higher scratch resistance compared to planes of other orientations. And the subsequent X-ray diffraction analysis reveals that in the vicinity of enameloid surface the hydroxyapatite(HAp) crystallites have a preferential orientation that (001) crystal plane is parallel to the occlusal surface. The superior wear resistance of the occlusal surface thus can be explained by the c-axis preferential orientation in the enameloid and the prominent wear resistance of (001) plane of HAp crystal, which is demonstrated by molecular dynamics simulation. And mechanism accounting for such prominence of wear resistance of (001) plane is addressed by theoretical modeling based on the classical wear theory.



(a) (b)

Figure 1. The normalized tangential forces as a function of the normalized depth. (a) In (010) plane, the rubbing force initially is smaller, when the normalized penetration depth reaches about 0.75, the cutting force becomes the smaller one. (b) In (001) plane, the rubbing force is always the smaller one.

Numerical Demonstration of Negative Thermophoresis of Nanoparticles in the Free Molecular Regime

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Thermophoresis is a transport phenomenon of small particles caused by temperature gradients. It has essential influences on various areas, such as aerosol industry, biology, and nanofabrication. Traditionally, it is well known that particles transport from high temperature to low temperature region. However, Wang and Li [1] analytically showed the existence of negative thermophoresis, where particles move from low temperature to high temperature in gas media, especially when the particle size is of nanometer. Due to the complexity of the interactions between particles and gas molecules, it is difficult to capture the real picture of the mechanism analytically. In this work, we use molecular dynamics simulations to study negative thermophoresis for nanoparticles. It is shown that negative thermophoresis can take place for nanoparticles and it depends on both the particle size and the molecular interactions between nanoparticles and gas molecules.

Acknowledgment

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Numerical Simulation of a Single Cell Flowing through a Narrow Slit

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The emigration of tumor cells from the blood stream through the vascular endothelium is a multi-step process, involving rolling on the blood vessel wall, adhesion to the endothelial cells and transmigration through the endothelial barrier (Strell et al., 2008; Reymond et al., 2013; Wirtz et al., 2011). Cell adhesion to vessel wall had been investigated both computationally and experimentally (Yan et al., 2012). Little is known about how invading tumor cells modulate the endothelium and physically penetrate the vascular wall.

Narrow slits between endothelial cells in the blood vessel walls provide the passages for tumor cells metastasis. Slit flow has been investigated (Omori et al., 2014; Freund et al., 2013) and the effects of viscosity ratio on the cell deformation behavior and transit time were discussed. In this study, to investigate the dynamics of a single cell through a narrow slit, a mesoscopic particle-based method—Dissipative Particle dynamics (DPD) was employed. The cell is modeled as a capsule with a thin membrane of triangulated network of springs (see Figure 1). The effects of slit size, cell shape and cell rigidity on the transit time of the cell were investigated. Furthermore, the elasticity of the endothelial cells was taken into consideration when the slit size is less than 4 μm. When the flow momentum is high enough, the cells deform easily and pass through the slit. The deformation of cell passing through the slit is shown in Figure 2. For all cases, the cells pass the slit at speed much less than that of plasma. With decreasing the slit size, the spherical cell becomes jammed despite decreasing its rigidity while the ellipsoidal cell with higher surface-area-to-volume ratio could pass through the slit. So the cell shape plays a more important role than the cell rigidity in the process of flowing through the slit with a small size.

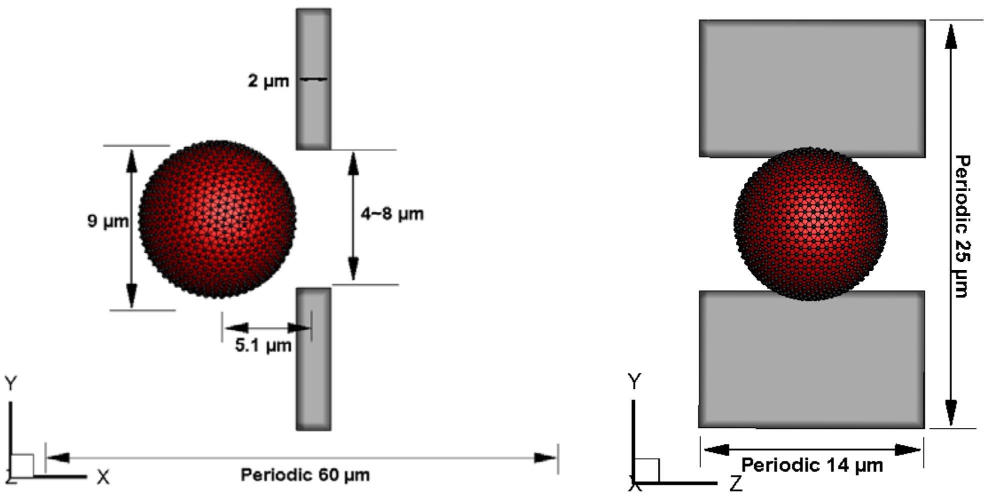

Figure 1. Schematic illustration of a spherical cell near a slit at initial time

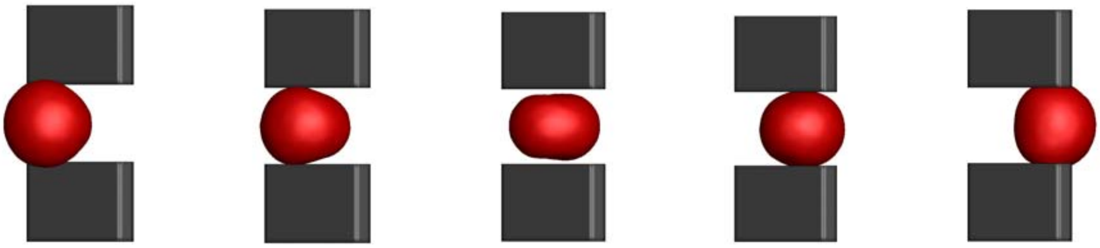

Figure 2. (a) t = 5 ms, (b) t = 15 ms, (c) t = 28.125 ms , (d) t = 38.44 ms, (e) t = 45.94 ms. Deformation of a spherical cell passing through the slit with 8 μm for body force f_x = 10 m/s^2 exerted on the fluid particles located on x > 15 μm and x < -15 μm

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Expansion and Migration of Dense Gas as Cause of Wenchuan Earthquake

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Since the occurrence of the devastating Wenchuan Earthquake in Sichuan, China on May 12, 2008, the author has actively participated in the investigation of the cause of the earthquake. Based on many phenomena that happened before, during and after the quaking, he has put forward his hypothesis of expansion and migrating of dense methane gas mass for the cause of earthquakes (Figure 1). The earthquake was caused by the rapid migration and expansion of highly compressed natural (methane) gas mass from deep crust trap to shallow ground via deep fault. The escaped dense gas has the mass ΔM, and volume ΔV and pressure P. It is escaped form the deep crust trap of dense gas with the mass M, volume V and pressure P. This hypothesis can well link all the observed phenomena together and can provide the deep-rooted theoretical basis for prediction of next damaging earthquakes.

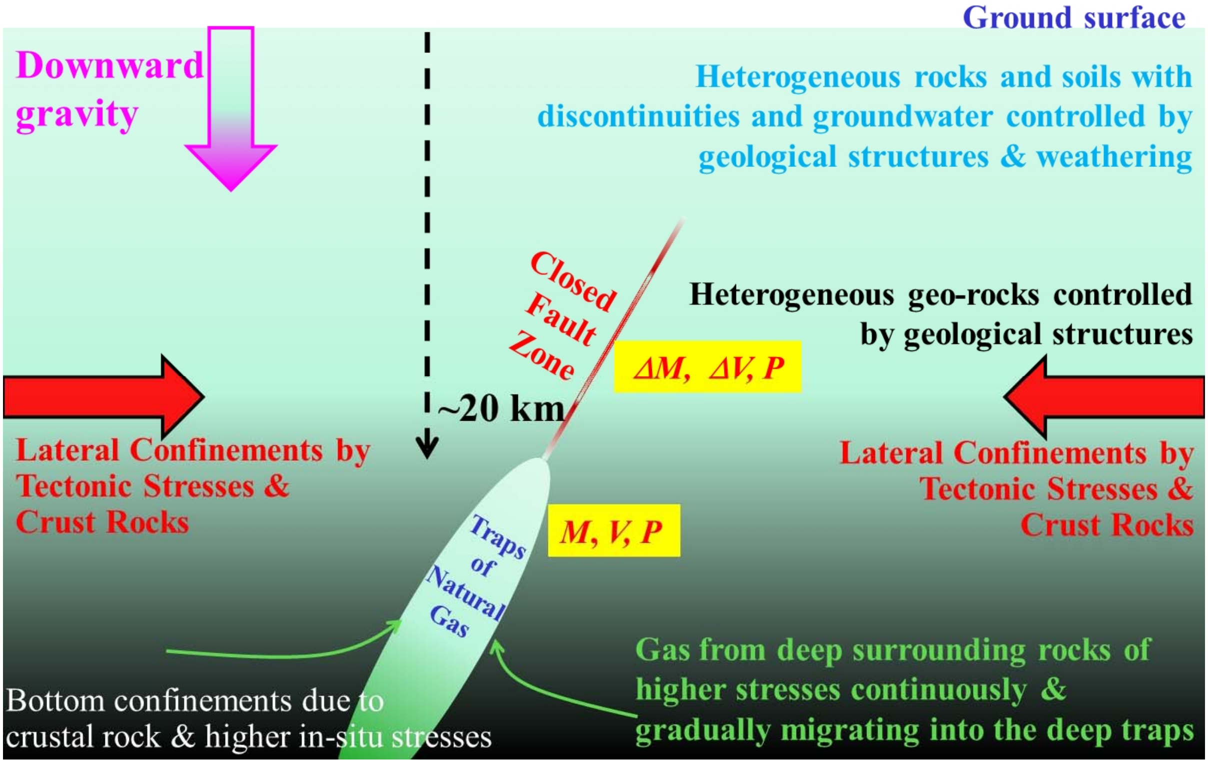

Figure 1. Mechanical model of active dense gas migrating and passive rock faulting for cause of earthquake.

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Stochastic Simulation of Spatially-distributed Earthquake Ground Motions

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The present study is among the first attempt to stochastically simulate spatially distributed ground motions over a region using wavelet packets and cokriging analysis. First, we characterize the time and frequency properties of ground motions using the wavelet packet analysis. The spatial cross-correlations of wavelet packet parameters are determined through geostatistical analysis of regionalized ground-motion data. Furthermore, using the developed spatial cross-correlation model and the cokriging technique, wavelet packet parameters at unmeasured locations can be best estimated, and regionalized ground-motion time histories can be synthesized. Case studies and blind tests using data demonstrate that the simulated ground motions generally agree well with the actual recorded data. It is also observed that the spatial cross-correlations of wavelet packet parameters are closely related to regional site conditions based on geostatistical analysis of eight well-recorded earthquakes in California, Mexico, Japan and Taiwan. The proposed method can be used to stochastically simulate regionalized ground motions for time-history analyses of distributed infrastructure and has important applications in regional-scale hazard analysis and loss estimation.

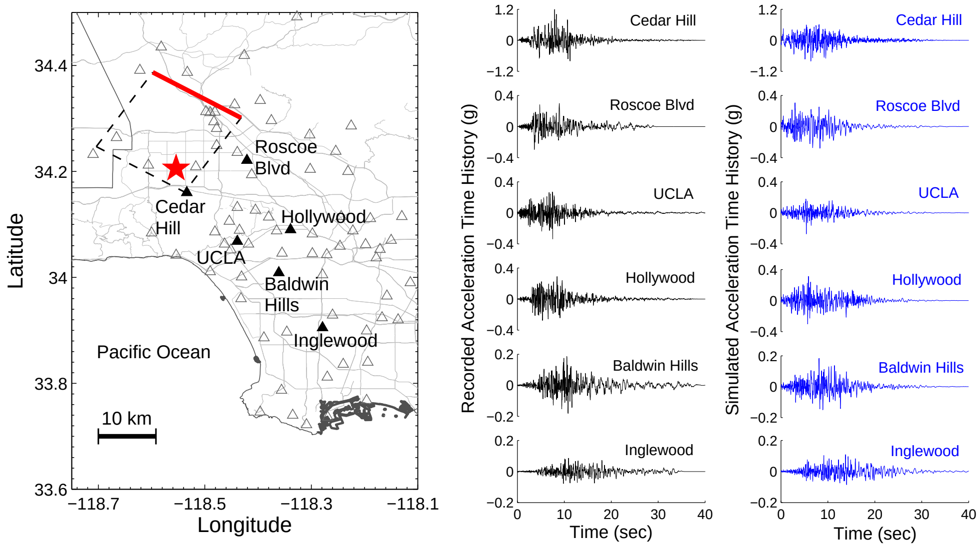

Figure 1. (a) A map of Los Angeles area, showing the six recording stations used in the blind test, the epicenter of the 1994 Northridge earthquake. (b) Recorded and (c) Simulated acceleration time histories at the six stations.

Acknowledgements

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Modal Identification and Model Updating of a Factory Building with Ambient Vibration Test Data Utilizing a Bayesian Approach

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Full-scale ambient vibration test (Au et al. 2012) and modal identification (Lam et al. 2014) provide valuable information about the dynamic properties of the target structure (e.g., natural frequencies, damping ratios, as well as mode shapes). The identified modal parameters are important in structural model updating, in which the set of uncertain model parameters (e.g., stiffness distributions) can be modified by minimizing the discrepancy between the measured and model-predicated responses. The updated model is very useful in solving various structural problems, such as structural design, vibration control and structural health monitoring. This research presents a comprehensive work on the modal identification and model updating of the 14-story factory building using ambient vibration test data. To get the dynamic response of the whole building, the ambient test was carried out in the three staircases of the building as well as on the roof slab. A total of 141 measurement locations were carefully planned before the test, which gives 423 measured degrees-of-freedom. Since only six tri-axial accelerometers were available for the field test, the entire vibration test was divided into multiple setups with at least two references in each setup. Finally, 12 setups were used for the measurements of the three staircases, and another 25 setups were used for the high resolution measurements on the roof for determining the dynamic characteristics of the entire factory building.

A Bayesian approach is adopted to handle the measured time-domain data and identify the modal parameters of the building. To gain an overview of the stiffness distribution along the height of the factory building, a simple shear-building model was constructed based on the design drawings of the building. The measured and model predicted modal parameters are not the same. Structural model updating was then employed to modify the inter-story stiffness of the building model utilizing the first six measured horizontal vibration modes following the Bayesian approach. The modal parameters from the updated model are almost the same as the measured ones.

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Bayesian Methodology in Railway Ballast Damage Detection Based on a Continuous Modelling Method

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Abstract: In general, railway ballast damage detection is heavily relying on visual inspection, which, however, is only able to identify surface damage of ballast, track geometry and rail twist problem. Ballast damage under the sleeper loading area and/or track shoulder, which can affect track stability and deteriorate riding quality, is extremely difficult to be detected through visual inspection. In this study, the model-based damage detection method, which relies on model updating treating ballast damage detection as an inverse problem, is proposed. The basic idea of the proposed ballast damage detection method is to use the measured modal parameters of the target in-situ sleepers to back-calculate the ballast stiffness. A straightforward way to model the distribution of ballast stiffness along a concrete sleeper is to divide the area under the sleeper into discrete regions (Lam et. al 2012; Lam et. al 2014), where the ballast stiffness within a given region is assumed to be a constant. Although this discrete-region model class is simple, the modelling error is large as ballast stiffness generally varies continuously along a sleeper and the stiffness discontinuity between the two regions is artificial. In this paper, a continuous modelling method is proposed to avoid the problem of discontinuous stiffness jumps. The uncertainties induced by modelling error and measurement noise are the major difficulties of vibration-based damage detection methods. In the proposed method, the Bayesian probabilistic approach (Lam et. al. 2014) is adopted to explicitly address the uncertainties associated with measured modal parameters. The proposed method of ballast damage detection was verified with vibration data measured from a full-scale ballasted track under laboratory conditions. The experimental verification results are encouraging showing that the proposed methodology is feasible in detecting the ballast damage under a sleeper and to estimate the corresponding percentage stiffness reduction.

Acknowledgements

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Multiscale Modelling of Failure in Saturated Sand

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We extend the hierarchical multiscale model developed earlier (Guo and Zhao, 2013, 2014, 2015) to consider the effect of pore fluid in granular media. In the multiscale computational framework, the finite element method is employed to solve the global momentum equilibrium equation of the fluid-solid mixture and the mass balance equation of the pore fluid flow. The *effective stress* of the granular skeleton at the material points of the FEM mesh is resolved by means of embedded discrete element simulations, which is further superposed with the pore water pressure to obtain the *total stress*. The implementation of the approach is first validated against 1D and 2D consolidation problems where closed-form solutions are available. It is further applied to the simulation of globally undrained biaxial compression tests on dense and loose sand specimens with high and low permeability. A localized failure mode is observed in the dense specimen, while a diffuse failure (liquefaction) is found for the loose specimen.

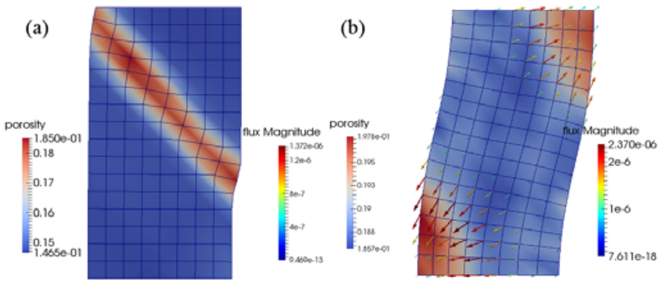

Figure 1. Multiscale modelling of (a) Localized failure mode in dense specimen, and (b) diffuse failure in loose specimen.

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Biham–Middleton–Levine Model in Consideration of Cooperative Willingness

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The Biham–Middleton–Levine (BML) model considering the cooperative willingness has been proposed to study the traffic flow on urban road network. Evolutionary game with cooperative willingness profile is introduced to deal with conflicts between disturbing neighbours. Simulation results suggest that imitating cooperative willingness could ease the effect of premature seizure on traffic flow due to the introduction of evolutionary games. Phase diagrams involving both strategic and cooperative willingness profiles have been investigated in details. Our findings also prove that, by imitating the more successful cooperative willingness instead of simply the more successful strategies, the evolution of cooperation is significantly promoted, hence improving the order of cooperation and relieving the potential of traffic jam and the pressure of traffic networks as well.

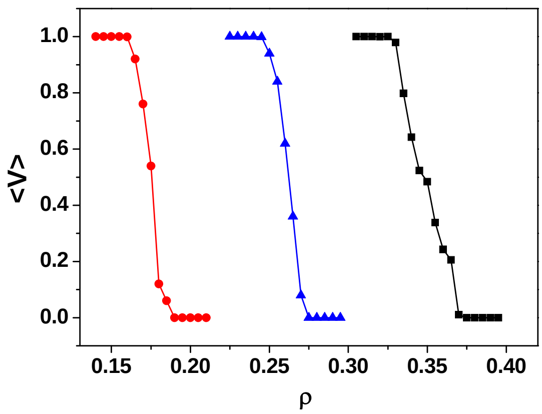

Figure 1. Average velocity <V> against density ρ in the original BML model (black), evolutionary BML model with strategy profile (red) and cooperative willingness profile (blue).

Acknowledgements

The work presented was partially supported by National Natural Science Foundation of China (Grant No. 11262003), the Hong Kong Research Grants Council (RGC)-General Research Fund (GRF) Grant, China (Grant No. CityU 118212), the Strategic Research Grant, City University of Hong Kong, China (Grant No. CityU-SRG7004176).

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Pre-cracked Response of the Rocks under Uniaxial Compression by Using X-ray Tomography

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Abstract: A rock is typically a heterogeneous and discontinuous material and its mechanical properties are governed by the discontinuity features of its microstructure. In this study an extensive experimental test program will be performed on pre-cracked specimens of different types of rock (e.g., granite, sandstone and shale) to investigate crack initiation, propagation and coalescence from frictional discontinuities under the unconfined compression condition by using in-situ x-ray tomography. A novel mini apparatus for unconfined compression test is being developed to scan the sample during loading. Micro-scale size specimens will be prepared with three different parallel pre-existing closed and open micro-flaws with a constant length 3 mm. During the loading process, the sample will be scanned at different loading steps until the specimen fails. Flaw angle will be changed corresponding to the direction of loading which may give different geometries. Fracturing process for the open and closed flaws will be compared.

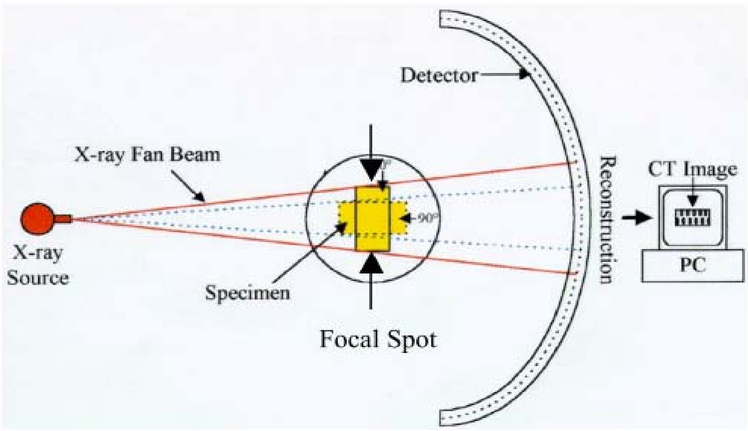

Figure 1. A typical X-ray tomography set up

Acknowledgements

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An Investigation on Micro-mechanism of Creep in Sands Using X Ray Tomography

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Abstract: Creep behaviour of sands plays a very important role in displacement pile engineering and it has been reported that particle sliding, rolling and progressive breakage are the main driving factors for the creep of sands. In order to investigate the micro-mechanism of creep in sands, a mini-triaxial apparatus has been under development recently to take full advantage of x-ray micro-tomography, which supports the in-situ scanning of sand samples under compression. Different stress levels (200kpa, 400kpa, 800kpa and 1200kpa) and stress ratios q / p' will be applied to both dense and loose completely decomposed granite (CDG) samples. The micro-structural changes of sand samples including particle size, particle orientation, void distribution and inter-particle contacts recorded during the creep test will be studied via scanning and image analysis in this study. The work will shed light on both complex shear strain and volumetric creep responses of sands.

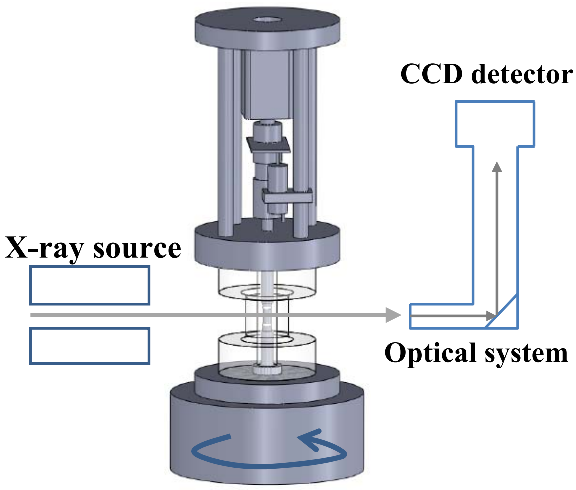

Figure 1. Schematic of x-ray tomography set-up for triaxial test

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Micromechanical Indictors for Post-liquefaction Behaviors of Granular Soil

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The post-liquefaction behaviour of granular soils during cyclic loading includes the jamming transition under constant volume constraint. Besides the density, the internal structure also plays an important role in determine the jamming transition. A new way to do the internal structure quantification is proposed based on the Radical Voronoi tessellation and cell shape description. The internal structure is quantified by two internal variables, degree of inhomogeneity and degree of anisotropy, which are independent to each other. To study the post-liquefaction behaviour, discrete element simulation is employed with 2D spherical particles under constant volume constraint. The relation between post-liquefaction behaviours and internal structure is investigated.

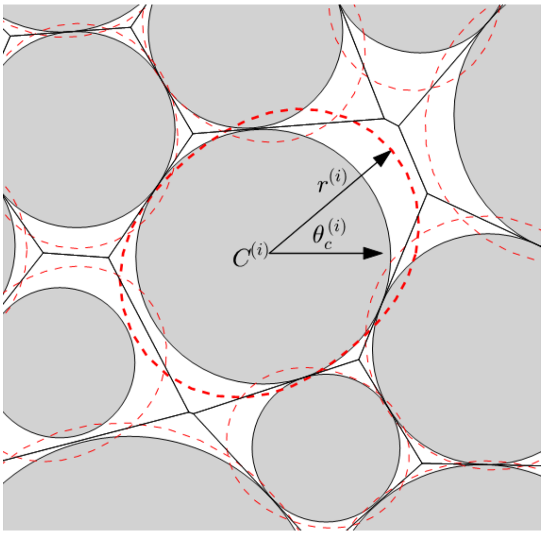

Figure 1. Radical Voronoi tessellation to the two dimensional granular packing (black solid line); Fourier expression to approximate the polygon-shaped cell (red dot line)

Acknowledgements

The study was financially supported by Hong Kong Research Grants Council (RGC) grant 620311and DAG11EG03G.

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Shear Strength and Unconfined Compression Strength of Unsaturated Completely Decomposed Granite Soil

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The shear strength of unsaturated completely decomposed granite (CDG) soil was measured in the laboratory by performing consolidated drained direct shear tests. A series of typical soil water characteristic curves (SWCC) of CDG soil under different net normal stresses were obtained by using an unsaturated direct shear apparatus. Experimental results show that both unsaturated shear strength and SWCC are significantly affected by the soil stress states. Shear dilation behaviour is observed significant at high suction and low net normal stress state, and the shear strength of unsaturated CDG soil increases with matric suction and net normal stress. Then available prediction model is employed to estimate the shear strength of unsaturated CDG soil at different stress states. Finally, based on the previous study of unconfined compression strength results of unsaturated CDG soil, the relationship of unsaturated shear strength parameters and unconfined compression strength was studied based on geometric relationship between unconfined compression strength and effective shear strength parameters, as shown in Figure 1. A new prediction model for unconfined compression strength of unsaturated soil was proposed using effective shear strength parameters and initial suction. The new prediction model is verified by experimental data and good agreement is found in the comparison.

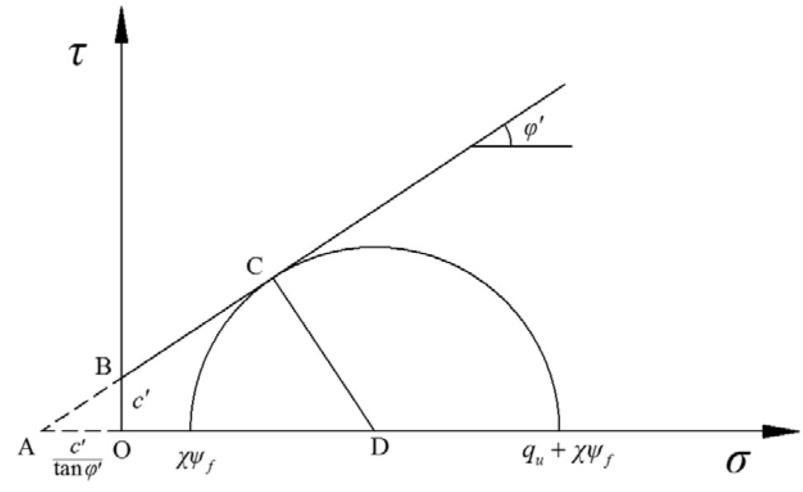

Figure 1. Geometric relationship between unconfined compression strength and effective shear strength parameters

Acknowledgements

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A Coupled CFD-DEM Simulation of Dam-Break

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A coupled Computational Fluid Dynamics and Discrete Element Method (CFD-DEM) approach (Zhao and Shan, 2013a,b; Shan and Zhao, 2014) is employed to simulate the dam-break problem in this study. The CFD is used to model the fluid flow by solving the locally averaged Navier-Stokes equation, and the DEM is applied to simulate the granular particle system based on Newton's second law of motion. The coupling between CFD and DEM is realized by considering interaction forces such as drag force, buoyancy force and viscous force between the fluid and the particles. The simulating setup of dam-break is based on the experiment (Greaves, 2006), as shown in Fig. 1. A mixture of viscous fluid and uniform particles is originally confined within a cubic tank. The breaking of dam is modelled by releasing the right confining wall. Four cases with different constituents are investigated based on using, respectively, a Herschel-Bulkley fluid-particle sample, a water-particle sample, a pure Herschel-Bulkley fluid sample and a dry particle sample. The obtained results are compared and discussed.

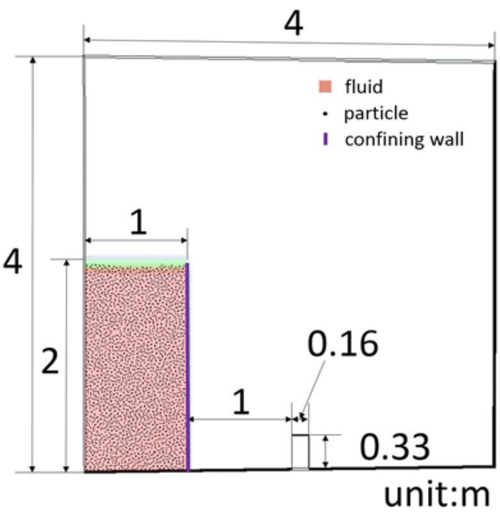

Figure 1. Numerical simulation model of dam-break.

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Multiscale Modelling of Compaction Band in Porous Sandstone

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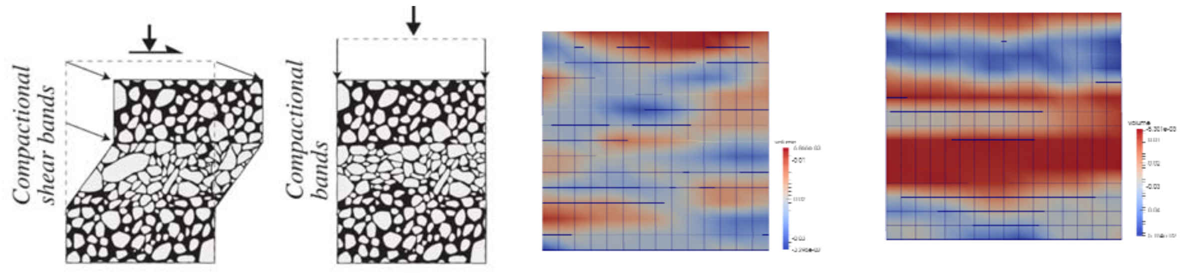
Localized compaction bands have been widely observed in highly porous sandstone which are of immense practical importance pertaining to hydrocarbon reservoirs, aquifers in porous rocks and borehole stability problems (Marketos and Bolton, 2009). Compaction bands may present in the form of pure compaction or mixed with shear (See Fig. 1a, Fossen et al., 2007). Cataclastic failure of grains, interparticle bond breakage and accompanied pore collapse are attributable to the formation of compaction bands in sandstone.



(a) Compaction bands in sandstone (Fossen et al., 2007) (b) Diffused failure mode (c) Compaction bands

Figure 1. Illustration of compaction band type (a) and multiscale simulation results of diffused failure mode (b) and compaction bands (c) (in terms of volumetric strain contour) under monotonic biaxial compression

A multiscale investigation of compaction bands in porous sandstone is presented in this study, based on the hierarchical multiscale approach recently proposed by Guo and Zhao (2013, 2014, 2015). In addition to linear contact law and Coulomb's friction, both normal and shear interparticle cohesion are considered towards the interparticle contact to simulate possible debonding process. Representative volume elements (RVEs) with big pores are generated to simulate highly porous granular media. In our simulations of biaxial compression tests both diffused failure mode and distinct compaction bands are observed. The physical mechanisms governing the formation of compaction band are discussed and are compared against the case of shear band. The roles of the strength and variation of interparticle cohesion, macro-void size and particle kinematics are examined.

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A New Implementation of Geometric Semantic Genetic Programing for Dam Safety Factor

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Geometric semantic genetic programming (GSGP) was proposed by Moraglio recently. However, the algorithm not save the formula for predication after training step in the processing (Moraglio, 2012; Castelli, 2013). It is a disadvantage to repeat using the same training sample for each time predication. We are through the formula extraction and storage, loading and calculating step to achieve GSGP and improve the algorithm without having to re-train in the same training sample for each time predication. The training step and each time prediction steps were separated to obtain high computational efficiency. In the procedure, the properties of the embankment dam as bulk density, cohesion, friction angle, slope angle, slope height, pore pressure ratios were regarded as input variables and the slope safety factor of the embankment dam as the output variable (Zhao, 2012). Based on GSGP, we established the prediction model of the embankment dam safety factor. The specific ways of the algorithm were provided for obtaining the embankment dam safety factor in the paper. The reference [4] data were used for learning and test samples as one instance in the research. The feasibility of the algorithm was discussed for predicating embankment dam safety factor. The results have shown good correlation between the prediction and the real value with the safety factor. In safety factor analysis, GSGP comparing with the conventional algorithms has high accuracy and great reliability.

Acknowledgements

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Crack Width Analysis of Reinforced Concrete Beams by Modified Discrete Crack Model

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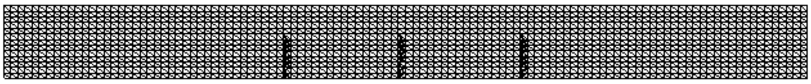
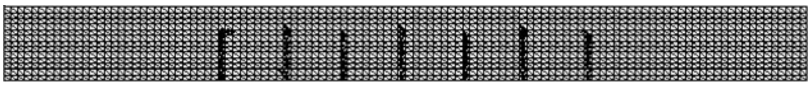
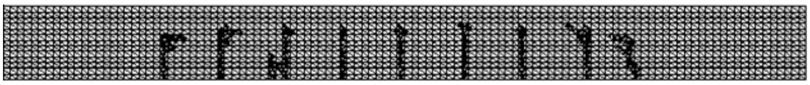
Crack widths are important considerations in both serviceability and durability design of concrete structures and should be evaluated to ensure compliance with design limits. However, crack width analysis cannot be done only by empirical formulas. It is because empirical formulas can only predict maximum crack width, but cannot indicate other information such as crack number and crack spacing. To obtain such information, finite element analysis has to be adopted. However, conventional finite element analysis has its limits in carrying out crack analysis. Particularly, the common smeared crack models, which do not realistically reflect bond-slip of steel reinforcing bars, would not give the correct crack widths. On the other hand, the discrete crack models are difficult to apply because of the need to adaptively generate discrete crack elements to follow the cracks formed during the loading process. In this study, a new finite element method for discrete crack analysis is developed. By transforming the conventional smeared crack model and introducing a new crack queuing algorithm, the method does not require the use of discrete crack elements. The steel reinforcing bars are modelled by discrete bar elements and their bond-slip is allowed for by using steel bar-concrete interface elements [1]. The crack queuing algorithm is employed to simulate the stress redistribution during crack formation and propagation [2]. The method has been implemented in a finite element programme developed by the authors and applied to analyse reinforced concrete beams in the literature. It is found that the computed crack number, spacing and widths are in close agreement with the measured results.



(a) Steel stress=63 MPa



(b) Steel stress=138 MPa



(c) Steel stress=172 MPa

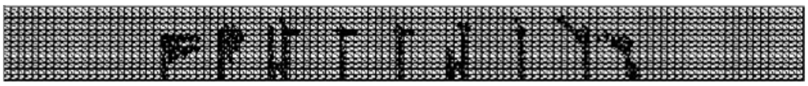


Figure 1. Crack patterns of beam 15-6-8-1 at different steel stresses by finite element analysis.

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Experimental Verification of Fracture-mode Map for Brittle Coatings

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Laminated structures, upon sufficiently high indentation load, tend to fracture either through ring cracking or radial cracking. Inspired by this observation, in this paper we systematically studied the factors determining the fracture modes of a bilayer structure under indentation. By analysing the stress field of a bilayer structure under indentation and applying the maximum-tensile-stress fracture criterion, we showed that the fracture mode of a bilayer structure depends on multiple factors including the mechanical properties and characteristic dimensions of both the bilayer and indenter. A fracture-mode map was theoretically developed, by which the facture mode can be predicted according to two dimensionless characteristic parameters of the indentation system. Experimental verification of the fracture-mode map was carried out by examining the fracture modes of the model fused quartz/cement bilayer system under indentation. The results exhibit a good agreement with the prediction by the fracture-mode map. Our finding may not only shed light on the mechanics accounting for the fracture modes of bilayer structures under indentation but pave a new avenue to combating catastrophic damage through fracture mode control.

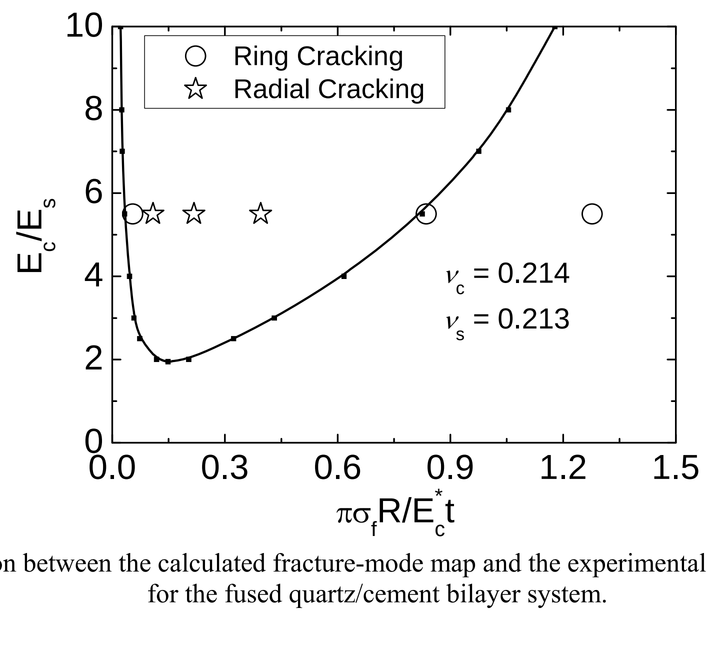

Figure 1. Comparison between the calculated fracture-mode map and the experimental results (scatter symbols) for the fused quartz/cement bilayer system.

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An Accelerated Grid-based BEM for Geometrically Nonlinear Problems

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The need for effective methods to model nonlinear problems with complex domains has raised a great challenge and significance in the development of numerical modelling and simulation techniques. For the solution of mechanical problems, the volume methods such as the finite element method have been the most widely used numerical techniques for many years. However, some limitations of these popular methods can be pointed out, for example, the burdensome pre- and post-processing since the entire domain has to be discretized; the requirement of extremely fine mesh with high quality in order to obtain the accurate results with high gradients; and the cumbersome way in problems with infinite domain.

On the other hand, the boundary element method (BEM) has been established as a powerful numerical alternative to volume methods in many fields of mechanics and other physical subjects beneficial from its reduced dimensionality. It is especially suited for problems governed by linear and homogeneous partial differential equations. However, the extension of BEM to non-homogeneous or nonlinear problem meets its bottleneck, as domain integrals will arise due to non-homogeneous /nonlinear terms. Effective evaluation of domain integrals become very crucial, since it may induce domain discretization which is burdensome for complicated domains, furthermore it losses one main advantage of the BEM, that is, the need for boundary-only discretization. Recently a Cartesian grid based direct integration method was proposed with the aim of retaining the boundary-only nature of the method [1-2]. The central idea is to replace the original volume integral with an integral of which the source function is continuous over the entire grid. As such the volume integration can be evaluated on the Cartesian grid directly without the need to identify and discretize the problem domain embedded inside the grid. The only downside of this new approach is the need for solving an additional linear boundary value problem defined in the original problem domain. Hence efficient algorithms need to be developed in order to apply this method to solving practical problems. In addition, the accuracy of the volume integration corresponding to the continuous source and its effect on the overall convergence rate of the method should be carefully studied. In this work, a systematic study of the complexity and the accuracy of the grid-based integration method for nonlinear problems in a 2-D setting will be presented first. Efficient algorithms are implemented to improve the overall efficiency of the method. Then this method will further be extended to solve 3D geometrically nonlinear elastic problems.

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The Improvement of Finite Element Model of a Rail-Sleeper-Ballast System using Measured Time-Domain Field Test Data

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A practical way for the detection of ballast damage under sleepers is a persistent problem, and remains in high demand in the railway industry. An accurate class of finite element models (FEMs) that is capable in reproducing the time-domain responses of the in-situ sleeper is important in the development of a ballast damage detection method. Usually, the responses calculated by the FEM, which was constructed on the basis of design drawings and specifications, do not match well with the experimental measured responses from field tests. It is believed that the discrepancies are mainly caused by (1) the uncertainties in geometry and boundary conditions, (2) the FE model discretisation, and (3) the variation in material properties. The first two items can be addressed by developing more "accurate" FE models. Then, the last item can be handled by model updating method for a given class of models. In this study, several classes of FEMs were tested to find out the most plausible model class for capturing the dynamic characteristics of the in-situ sleeper. In the proposed method, an in-situ sleeper is modelled as a Timoshenko beam on an elastic foundation, as shown in Fig. 1. The effects of the left and right rail pads and rails are modelled as two equivalent spring-mass systems, and the ballast stiffness is modelled as a distributed spring along the length of the sleeper. The measured vertical vibrations at different locations on the in-situ sleeper were matched with the model-predicted responses from the FE model to improve the accuracy of the model.

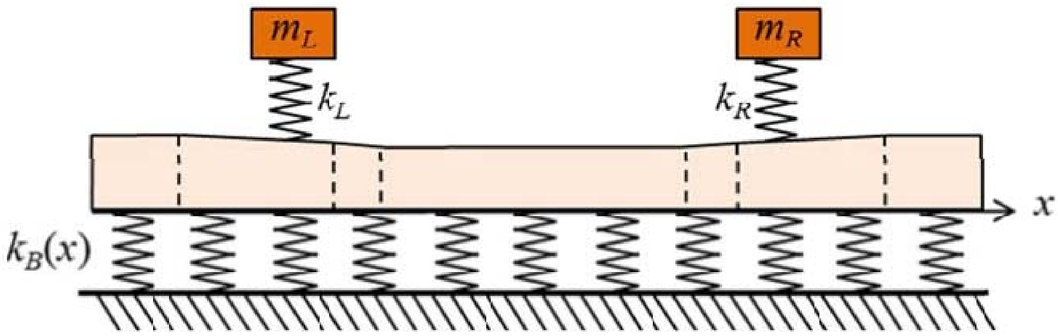

Figure 1. The selected model class of the rail-sleeper-ballast system

Acknowledgements

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Bayesian Model Updating Using a Markov Chain Monte Carlo Algorithm

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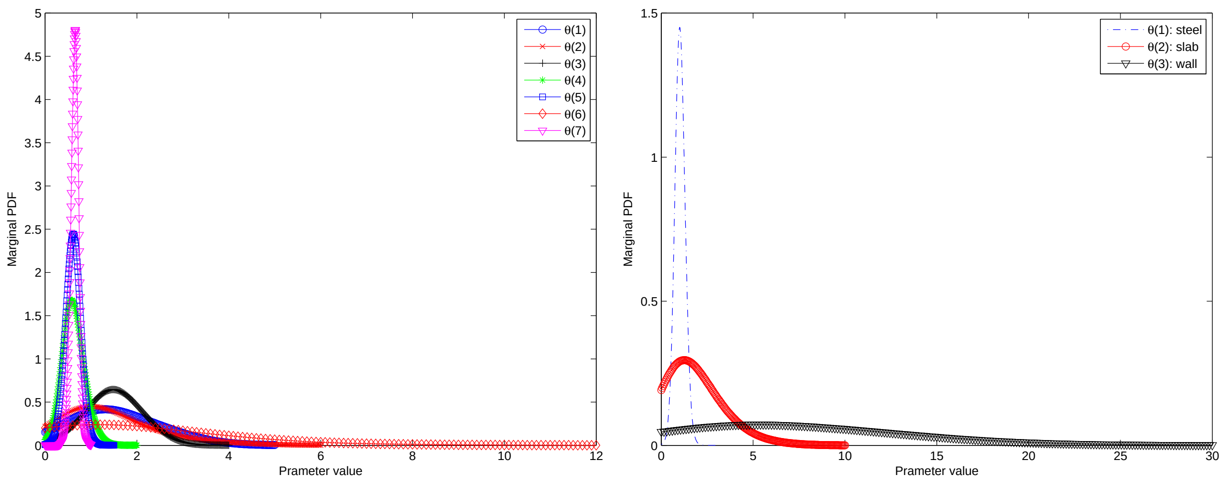
Structural health monitoring (SHM) of civil engineering structures based on measured modal parameters includes three main components: ambient vibration test, modal identification and model updating. This paper discusses these three components in detail and proposes a general framework for practical SHM. First, a fast Bayesian modal identification method based on fast Fourier transform (FFT) is introduced for efficiently extracting modal parameters together with the corresponding uncertainties from ambient vibration data. A recently developed Bayesian model updating method using Markov chain Monte Carlo simulation (MCMCS) is then discussed. To illustrate the performance of the proposed modal identification and model updating methods, a scale-down transmission tower and a coupled-slab system of a real structure were investigated. Ambient vibration tests were conducted on the target structures to obtain modal parameters. By using the measured modal parameters, model updating was carried out. The objective was to maximize the posterior PDF $p(\boldsymbol{\theta}|\boldsymbol{D})$, where $\boldsymbol{\theta}$ is the uncertain structural parameter vector and $\boldsymbol{D}$ is the measured modal parameters. Since $p(\boldsymbol{\theta}|\boldsymbol{D})$ is usually only known up to a scaling constant, a MCMC-based algorithm is proposed to update the posterior PDF. Various levels of MCMCS were conducted. In each level, an intermediate PDF (or bridge PDF) which will finally converge to the target posterior PDF is constructed. The proposed MCMC-based algorithm can efficiently evaluate the posterior marginal PDFs of the uncertain parameters (see Figure 1) without calculating high-dimension numerical integration, which provides posterior uncertainties for the target systems.

Acknowledgements

The work was supported by the Research Grants Council of the Hong Kong Special Administrative Region, China (Project No. 9041889 (CityU 115413)). The authors are thankful for the support.



(a) (b)

Figure 1. Posterior PDFs of uncertain parameters: (a) scaled-down transmission tower, (b) coupled-slab system.

Improved Analysis for Gas-Filled Encapsulated Thermal-Acoustic Transducer

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A kind of thermal-Acoustic transducer is modelled via basic calculus method. Both accurate analytical solutions and numerical results are obtained, explained and compared with each other. Differing form conventionally generated acoustic wave, thermal-acoustic wave presents a wider range of frequency, higher sound pressure level and simpler manufacture requirements even high quality of ultrasound might also be emitted under some extreme experiments. After applying AC electricity, nano-tube thin film works as the core component, inert gas is filled to enforce thermal-acoustic effects, and one end of transducer is to absorb acoustic wave also to ensure dispersion in only one direction.

In this paper, an improved analysis to increase accuracy of conventional results is discussed. Based on some relevant works, further approximation is discovered and more work has to be focused. The results will re-shape some numerical results derived via the simplified analysis.

Acknowledgements

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Thermoresistive Micro Calorimetric Flow Sensor Array by using CMOS MEMS Technology

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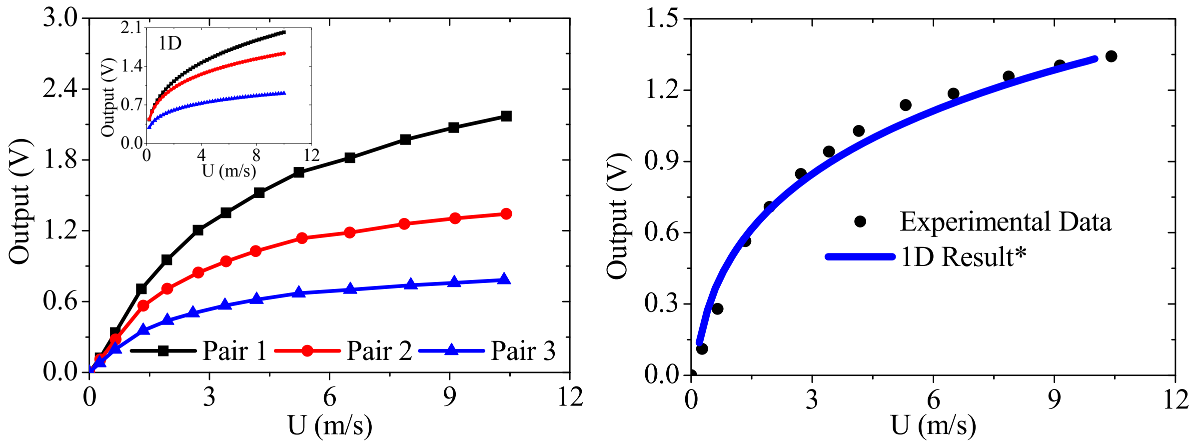
Based on the design analysis in our previous work [1], a micro calorimetric flow sensor array of three different sizes (Pairs 1-3) is successfully designed and fabricated by the standard CMOS MEMS technology. The flow sensor chip is then tested within a PMMA flow channel, and operated in CT mode (50K) with the nitrogen as flow fluids.

The testing results show that a low-power consumption (<2.77mW) and high sensitivity (0.543V/(m/s) for Pair 1) sensor design is achieved; meanwhile, the scaling analysis shows that the sensing elements closer to the heater could gain a better output and sensitivity for large velocity as shown in Figure 1(a). The experimental results could be explained by 1D model analysis. With the assumed fully developed Couette flow [2], the developed 1D model for describing the sensor's behaviour in packaged flow channel can be presented as:

$$\left(k_s t+\frac{1}{2}k_f\delta_t+\frac{1}{2}k_{f1}h\right)\frac{d^2T(x)}{dx^2}-\rho C_p U\frac{dT(x)}{dx}\left(\frac{\delta_t^2}{h_c}-\frac{\delta_t^3}{2h_c^2}\right)-\left(\frac{k_f}{\delta_t}+\frac{k_{f1}}{h}\right)T(x)=0$$

Obviously, the general behaviour of flow sensor is well captured by 1D analysis as shown in Figure 1. Therefore, the proposed 1D model is validated by experiments results and could be very useful for design optimization of calorimetric flow sensors in the future.



(a) (b)

Figure 1. Testing of CMOS TMCF sensor and its comparison with 1D analysis: (a) 1D and experimental scaling analysis for three pair of upstream and downstream sensors. (b) Comparison of 1D result with experimental data for Pair 2 sensor.

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Sensitivity Study of the MEMS Microphone with a Composited Layer Diaphragm

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Abstract: Microphones which convert the acoustic wave into electrical output have exhibits many important applications in our daily life, such as mobile phones, tablet PC, labtop computers, etc. MEMS condenser microphones have attracted more research interesting due to low cost, high sensitivity as well as low power consumption. A 1D model of silicon micromechanical condenser microphones has been developed to describe the performance of the device, and here we investigated the feasibility of the proposed model by considering the PolyMUMPS fabrication process, widely used for various MEMS devices. Based on the process specification, the diaphragm of the microphone will be composed of two layers (silicon nitride and polysilicon). Compared with single-layer design, the two composite layers made by different materials will complicate the mechanical behavior when they vibrate under the acoustic input pressure. Thus, the effective stiffness of the diaphragm was modified in the model to meet such situation, and also, numerical simulations of a FEM model by using COMSOL was performed to validate the effective mechanical property as shown in Figure 1. Finally, the analytical sensitivity of the MEMS microphone by using PolyMUMPs process was found to be around -75 dBV/Pa (1 kHz and 94 dBSPL) before the voltage amplification as given in Figure 2. It shows about 8 dBV/Pa improvement on sensitivity over previous single layer device model.

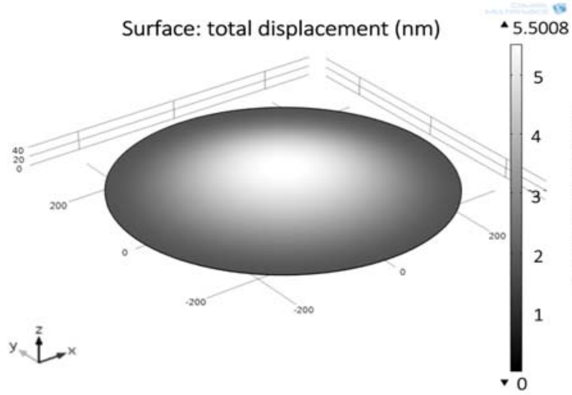

Figure 1. Simulation of the composited diaghragm.

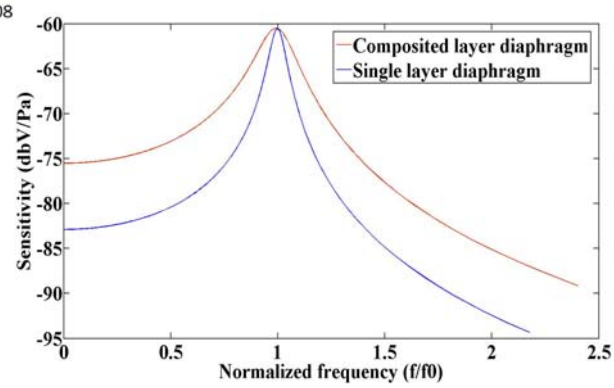

Figure 2. Sensitivity comparison between composited layer and single layer diaphragm

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Design of Micromachined Condenser Microphones with Concave Backplates

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This paper presents the design of MEMS condenser microphones using concave back plates. In general, the sensitivity of traditional fixed membrane boundary microphone depends on the dimension of the diameter of the membrane and the effective diaphragm area. In order to obtain higher sensitive, we have designed concave backplate condenser microphones with simple construction and few masks. We propose to reverse the fabrication steps to have the membrane on the bottom and then build the cavity and backplate on the top. This allows us to form the concave backplate on top of the reflowed photoresist in a convex spherical shape using the electroplating technique. After removal of the sacrificial photoresist to form the microphone cavity, the membrane is released by single-side wet etching to remove the backside silicon substrate. Since the device side remains dry, there is no membrane stiction problem caused by drying inside the cavity, which can realize a thinner and bigger membrane. By using the concave backplate to increase the effective area of the membrane, it can increase the effective capacitance to improve the sensitivity of the microphone.

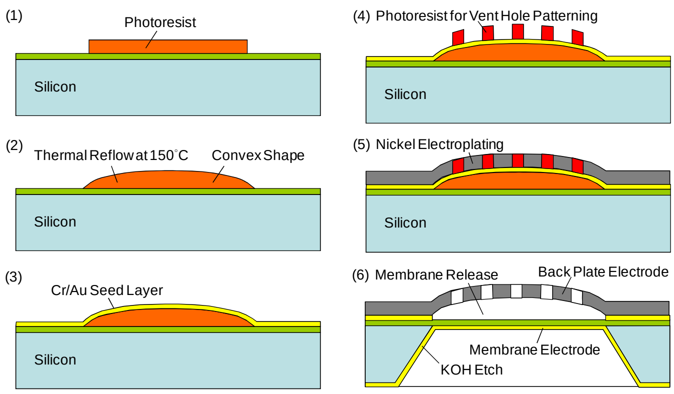

Figure 1. Microfabrication process of the microphone:

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A Capacitive Micromachined Ultrasonic Transducer (CMUT) Array with Single Layer Graphene Membrane

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A CMUT with graphene membrane is reported. CMUT membranes were commonly made from very thin silicon nitride or metal material. To date, no graphene CMUT has been successfully done. In this study, we use a photo mask for the cavity pattern to make a 10um layer SU-8 or EPON on the silicon substrate. Then we will transfer a single layer graphene directly to be attached to the SU-8 or EPON cavity layer to form the CMUT with graphene membrane. The resonance frequency is measured to be 95Mhz in air.

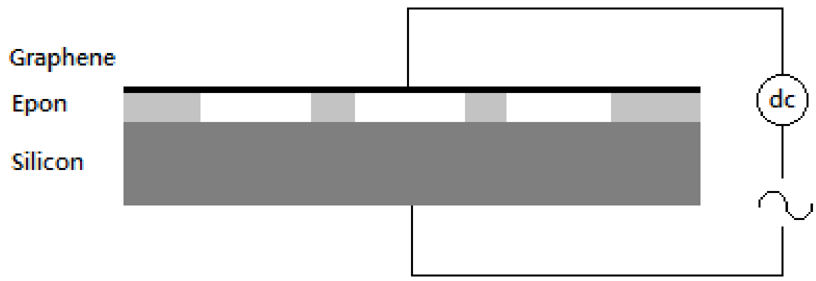

Figure 1. Schematic of the CMUT with graphene membrane.

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A Micro-electro-mechanical Switch for Power Applications

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Micro-electro-mechanical systems (MEMS) have found applications in a wide range of industrial and medical products with the advantages of small dimensions, batch fabrication, low power consumption, etc. Among them, MEMS switches have the potential to serve in many power applications where traditional macro switches and semiconductor power transistors are not applicable due to problems such as dimension and breakdown. Power switch is expected to carry higher current. However, to achieve this goal, traditional macro switches have to use more and more energy because the on-state resistance is larger and larger.

After MEMS switches were proposed in 1979, they were mainly used in RF systems. Only a limited number of structures were proposed for power applications. Until now, several issues such as on-resistance, stand-off voltage, reliability, etc. still impose limitations for power micro-electro-mechanical switches.

Several actuation methods such as piezoelectric actuation, thermal actuation, magnetostatic actuation, shape-memory alloy actuation and electrostatic actuation, have been proposed for MEMS applications. Considering reliability and practical purpose, the proposed switch uses electrostatic force to control the cantilever, resulting in on and off states. The structure which consists of a substrate, three metal electrodes on the substrate, a cantilever, and a tip contact is shown in Figure 1.

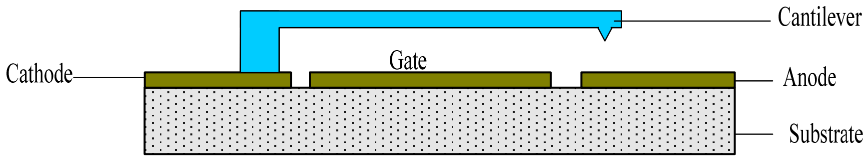

Figure 1. Structure of a micro-electro-mechanical switch.

Acknowledgements

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LOCATION MAP

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Ngau Tau Kok 牛頭角：		104
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Hang Hau 坑口：		11, 11M, 11S
Po Lam 寶琳：	91M	11S, 12

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