Yielding, Jamming, and Rheology of Granular Avalanche

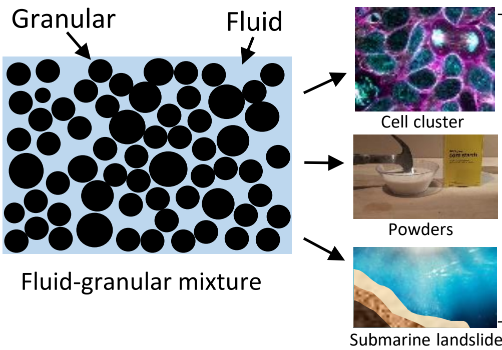
Ge Zhuan

Supervisor: Sergio Andres Galindo Torres

Man Teng

E-mail: gezhuan@westlake.edu.cn

Introduction



1.How do the fluid-granular mixtures flow?
Rheological law

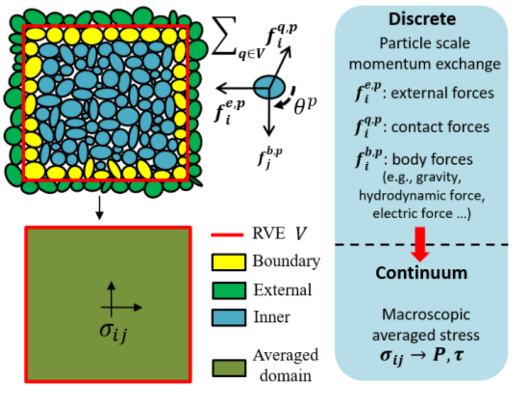
2.Solid-like to fluid-like (Yielding) ?
Jammed→Fragile →Flow

3.Fluid-like to solid-like ?
Flow→Fragile →Jammed

Fluid-granular mixture flows play a crucial role in various natural and engineering systems, ranging from cell clusters to debris flows, landslides, and particulate flows in the chemical engineering and food processing. However, complex particle-particle interactions and fluid effects poses significant challenges in understanding the yielding, jamming transition, and rheology of granular assemblies, necessitating the development of comprehensive and specific governing laws.

During my doctoral studies, I have focused on the unifying rheology of fluid-granular mixtures and have gained substantial experience in numerical modeling (from micro scale to macro scale), theoretical analysis, and experimental design. My research has involved: (1) we proposed a length-scale based dimensionless number, which can unifying the solid fraction and the apparent frictional coefficient of the fluid-granular mixtures. (2) We proposed the expression of the stress of fluid-granular mixture under random force field, and give the specific contributions of each force field. (3) We use the proposed dimensionless number to unify the yielding, jamming transition, and rheology of transient submerged granular avalanche.

Averaged stress in submerged condition (Contributions of each force field)

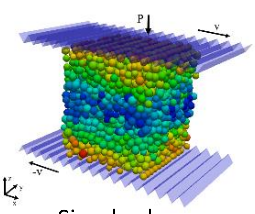


We use Hamilton's principal of at least to derive the averaged stress of granular assemblies under complex force fields. And triaxial tests are implemented to validate the result by LBM-DEM simulation. The main contributions are as follow:

- Derivation and validation of the averaged stress for submerged granular condition.
- Quantification of the contribution of various force fields (e.g.: hydrodynamic forces, magnetic forces …) to the averaged stress.
- Verification of the difference between pore water pressure and the real fluid effect on the solid part.

[Ge, Z., Man, T., & Galindo-Torres, S. A. (2023). Mean stress tensor of discrete particle systems in submerged conditions. IJSS, 271-272, 112239. doi:https://doi.org/10.1016/j.ijsolstr.2023.112]

Unifying rheology of fluid-solid mixture from inertial to viscous regime



Simple shear

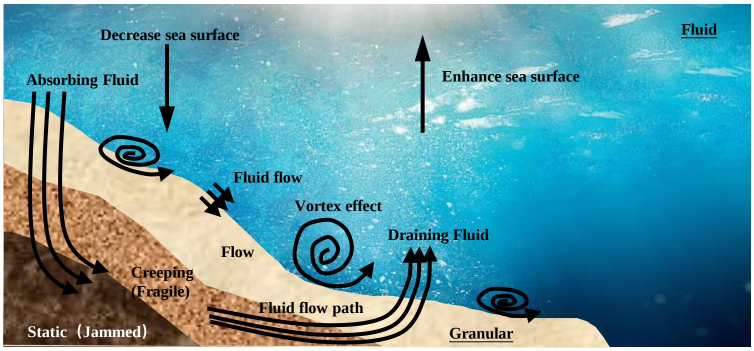
- We proposed a new dimensionless number based on length scale ratio $G(\eta_f, d, \rho_s, P, \dot{\gamma})$, which unified the rheology of fluid-solid mixture under different confining pressure, shear rate, fluid, and solid properties for both our simulation data and other published experimental data in a steady state.
- The new dimensionless number can naturally transform into the pioneers' works with the changing of the Stokes number (the number measured the effect of fluid and inertial), such as the inertial number when fluid put no effect and viscous number when fluid effect is dominate.

Based on this work, we can conveniently derive the relevant dimensionless numbers that govern the behavior of more complex systems, such as unsaturated granular assemblies or granular systems with the presence of magnetic forces.)

Flow regimes	I, J, K relationships	$G(\eta_f, d, \rho_s, P, \dot{\gamma})$
Inertial ($St \rightarrow \infty$)	$(\phi_c/\phi - 1) \propto I$ [GDR MiDi et al ,2004, EPJE]	$\lim_{St\rightarrow\infty} G^{0.5} = I$
Viscous ($St \rightarrow 0$)	$(\phi_c/\phi - 1) \propto J^{0.5}$ [Boyer et al ,2011, PRL]	$\lim_{St\rightarrow 0} G^{0.5} = J^{0.5}$
Visco-inertial ($St \approx 0 \rightarrow \infty$)	$(\phi_c/\phi - 1) \propto K^{0.5}$ [Trulsson et al ,2012, PRL] ($K = J + \lambda_0 I^2$ with fitting parameter λ_0)	$G = 12(J + \lambda(St) I^2)$ (with no fitting parameter)

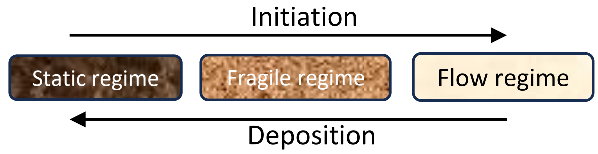
[Ge, Z., Man, T., Huppert, H. E., Hill, K., & Galindo-Torres, S. A. (2022). Unifying Lengthscale-Based Rheology of Dense Granular-Fluid Mixtures. (Submitted to Physical Review Fluids<letter>) doi:10.48550/arXiv.2210.0874]

Transient Granular Avalanche



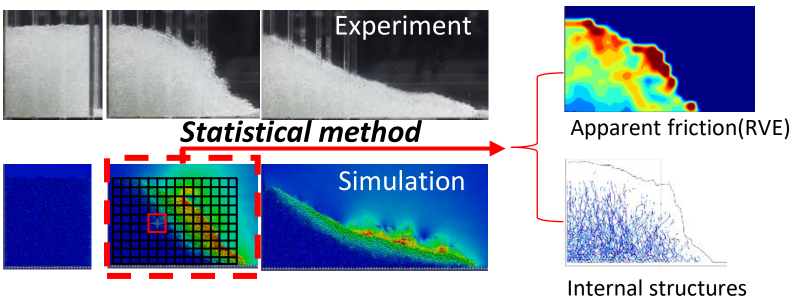
In a submerged granular avalanche, the following key physical process happens:

1.Phase transition



2.Fluid-granular flows

Both experiment and numerical simulation (LBM-DEM) of submerged granular collapse are implemented. We discretize the whole flow regime into numerous represent element (RVE), and calculate the averaged stress (proposed in [*Ge, Z, et al, 2023, IJSS*]) , strain, and solid fraction. Then we probe the transient rheology, phase transition of the granular mixtures with the dimensionless number $G(\eta_f, d, \rho_s, P, \dot{\gamma})$ we proposed in our previous work.

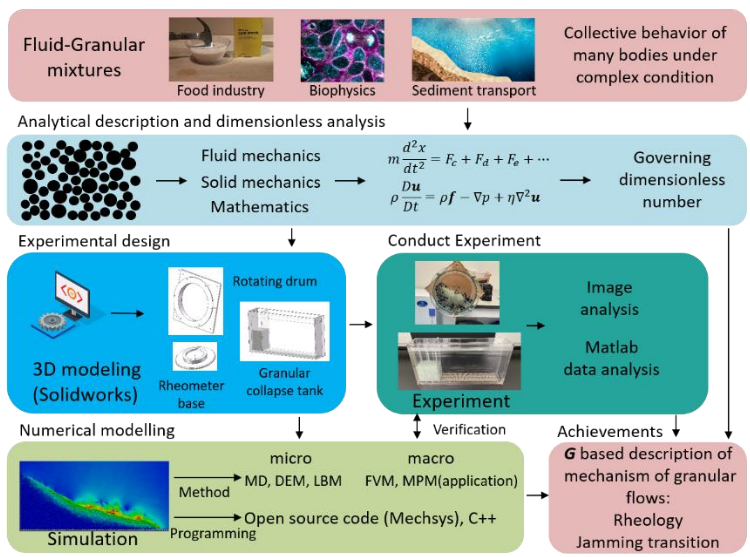


- In the flow regime, G can unify the rheological relations in a *transient granular flows*.
- When $G > G_0$, the granular flow transform into the flow regime from the fragile regime.

[We are working on the manuscript of this part of work.]

Expertise

- Proficient in numerical simulation techniques, including Molecular Dynamics (MD), Discrete Element Method (DEM), Finite Volume Method (FVM), Material Point Method (MPM), and Lattice Boltzmann Method (LBM).
- Extensive experience in experimental design, specifically utilizing 3D software such as Solidworks, to design and create experiments.
- Skilled in theoretical analysis using first principles and mathematical approaches to gain deep insights into complex phenomena and establish a strong theoretical foundation for research investigations. With the definition of the contribution of each force field, it is convenient to investigate how does a specific force field effect the flow behaviors of a specific granular materials, and control the materials by this force field.
- Developed a novel dimensionless number to characterize the behaviors of discrete granular systems, emphasizing the significance of length scale ratio in understanding the unique features and properties of disordered materials.



Research interests

Probing granular physics: Jamming, rheology

In my research pursuits, I am deeply interested in exploring the underlying physics of granular systems. Moving forward, I am committed to further investigating their phase transitions and uncovering the fundamental rheological laws governing their behaviors. To achieve this, I plan to employ a multidisciplinary approach that encompasses experimental studies, theoretical analysis, and numerical simulations. Additionally, I aspire to extend my knowledge and expertise in granular systems to the realm of soft materials. Specifically, I am keen on exploring the applications of these principles in areas such as soft robotics, civil engineering, and understanding the behavior of biological entities such as bacteria and cells.

Soft materials:

By utilizing specific force fields, I aim to control and shape the deformation of granular materials. Additionally, I am interested in leveraging the phase transition behavior of granular media for various applications, including soft robotics, 3D printing, and optimizing the design of fluid equipment. These applications can benefit from an in-depth understanding of the phase transition phenomena exhibited by granular materials.

Civil engineering:

Earth's landscapes are shaped by the interplay of granular-fluid mixtures. Countless interactions between discrete granules and fluids, driven by external forces, give rise to diverse features like river channels, mountains, and deltas. My goal is to uncover the dynamics and structures of these landscapes across scales, employing rheological laws. Furthermore, I aim to apply these laws to predict significant macroscopic natural events, including submarine landslides and mountain creep.