Research Report

Fracture-Matrix Interaction from Pore-Scale Direct Numerical Simulations (DNS)

Feng Xiao, Colorado School of Mines

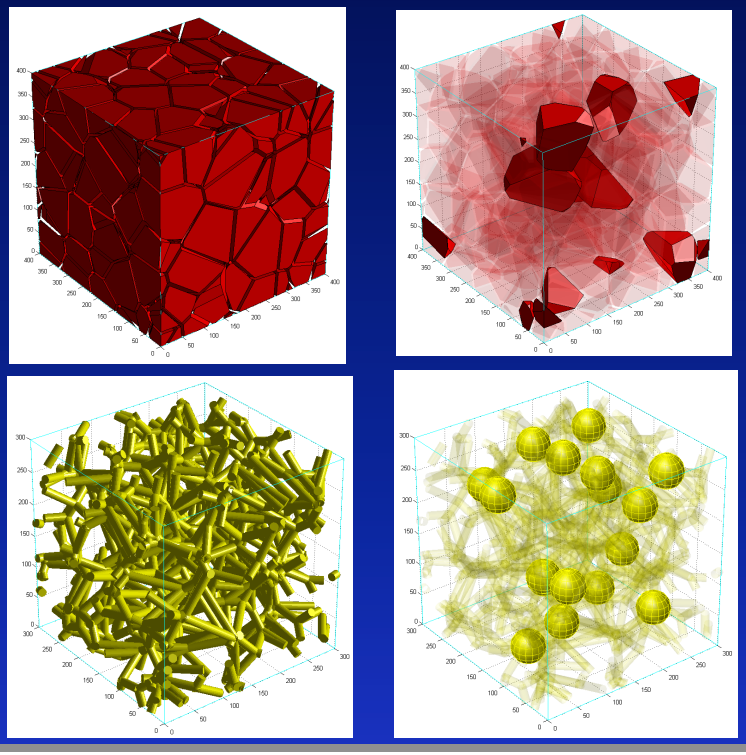
Outline

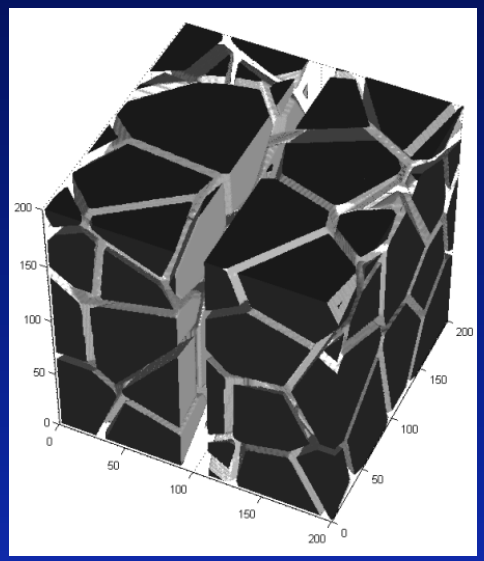
- Geometry models and lattice Boltzmann DNS
- Porosity and permeability relation
- Heterogeneous porous media under stress
- Flow in the "fracture" and flow in the matrix
- Conclusions

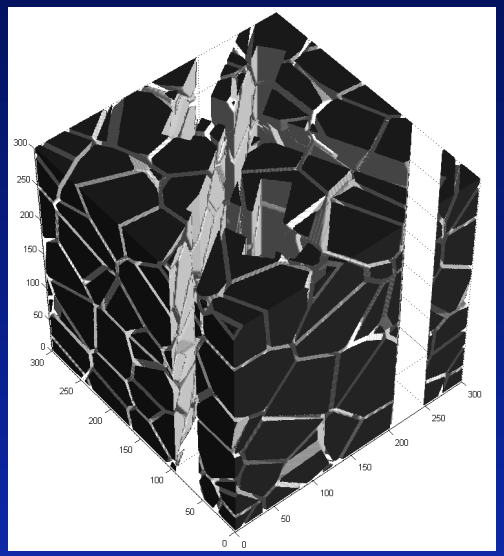
Geometry models

The geometry models of porous media are generated from Voronoi diagrams (a spatial decomposition method).

- Heterogeneous geometries: vuggy and fractured

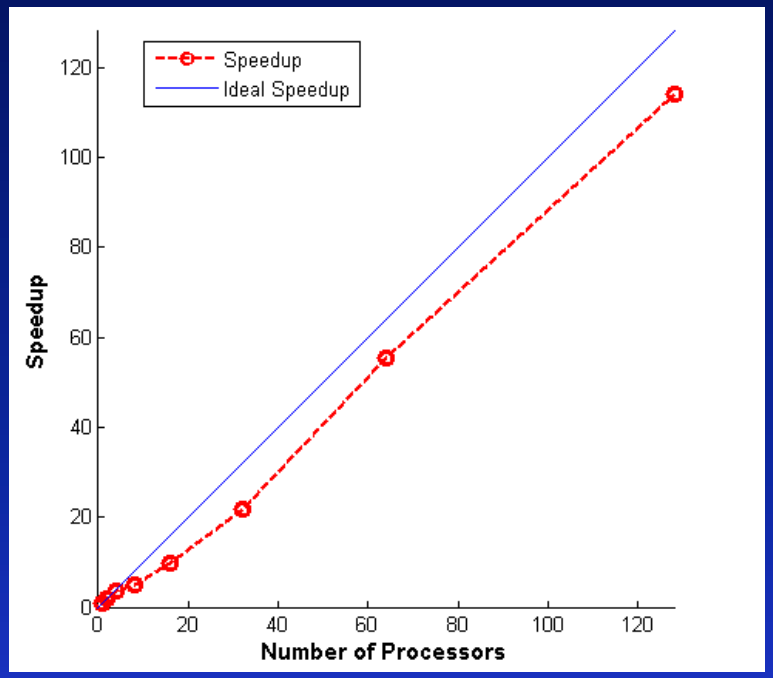




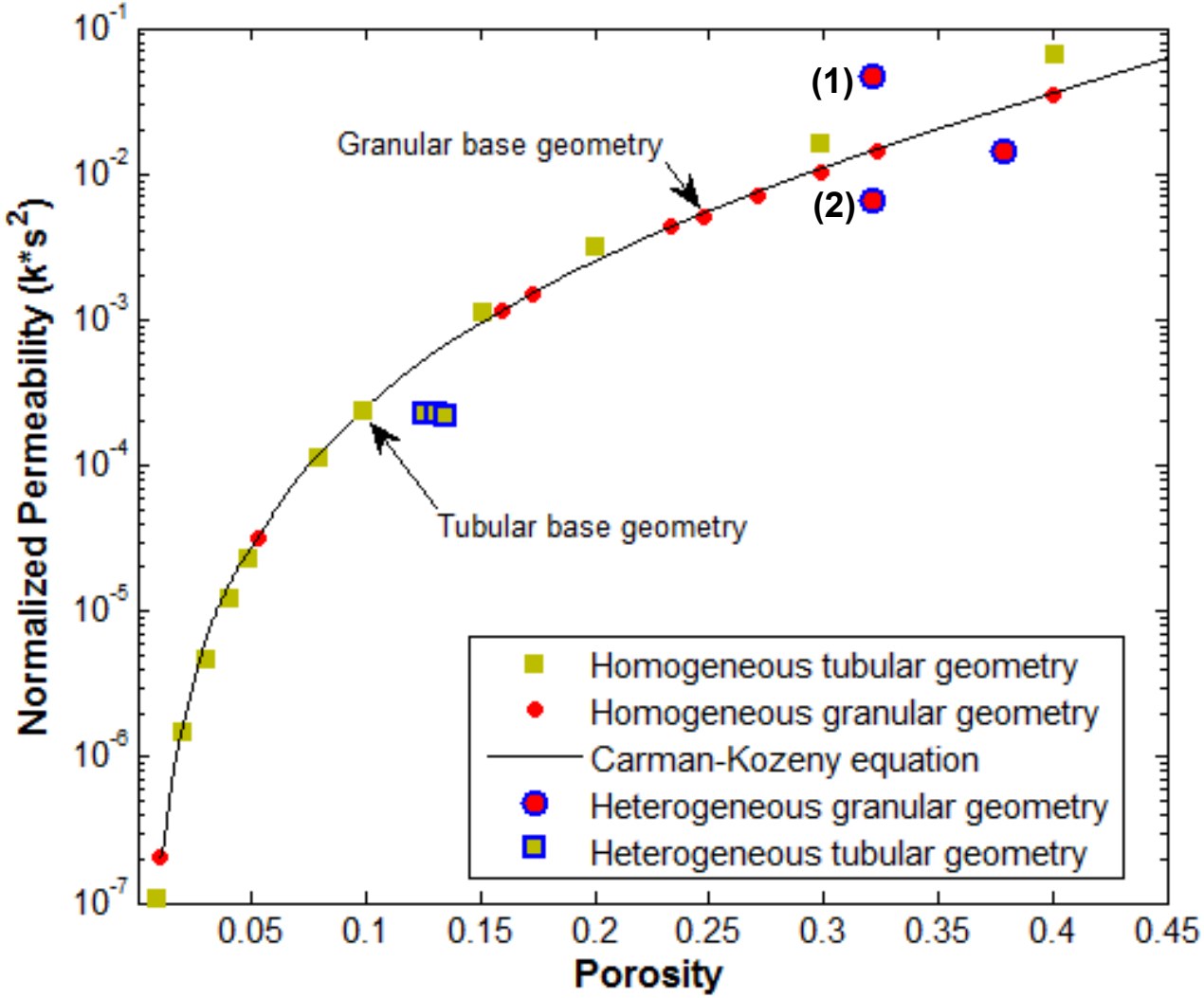


Lattice Boltzmann DNS

- Lattice Boltzmann method
  - Solves Navier-Stoke equation
  - Different from traditional CFD methods (FD, FE, FV)
  - Easily handles complex geometries, e.g., porous media
- Parallelized simulator
  - Massively parallel on distributed -memory clusters (MPI)
  - near-linear parallel speedup



Porosity-permeability relation



(1) Connected fracture

(2) Disconnected fracture

Other heterogeneous geometries are voggy

Carman-Kozeny coefficient is 5

Heterogeneous porous media under stress

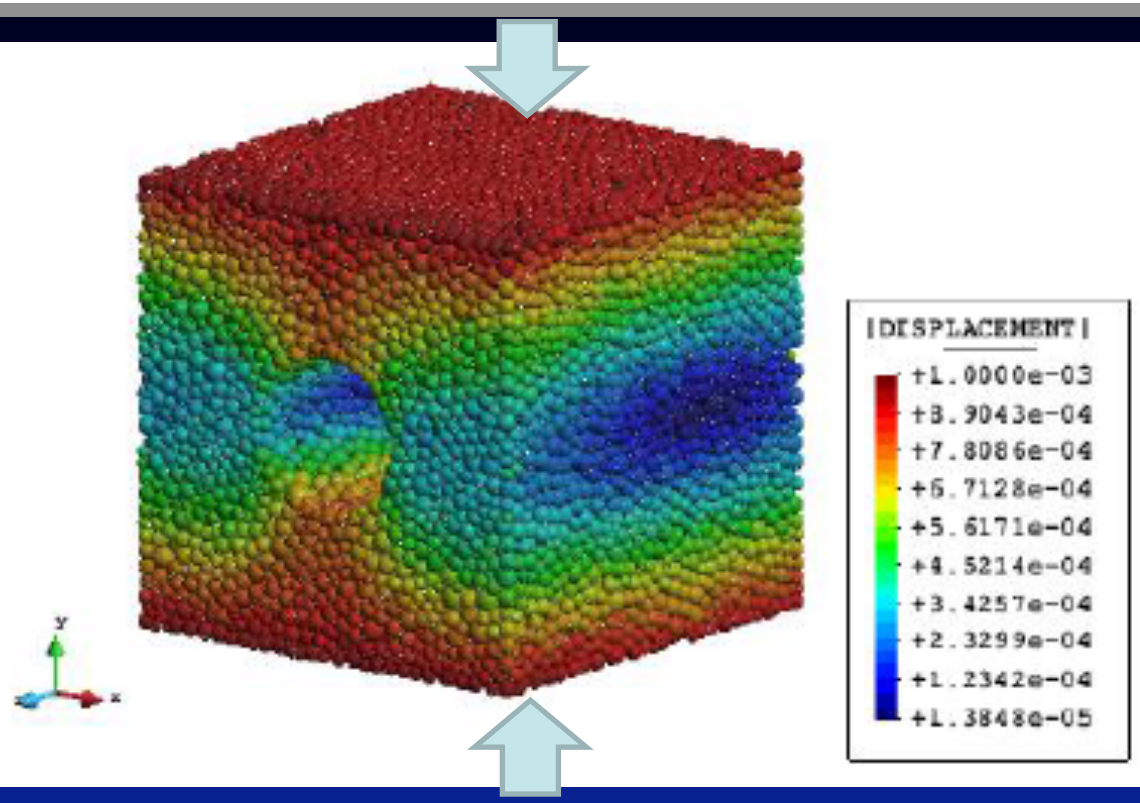


Figure: Distribution of vertical displacement generated by the simulation of Discrete Element Method

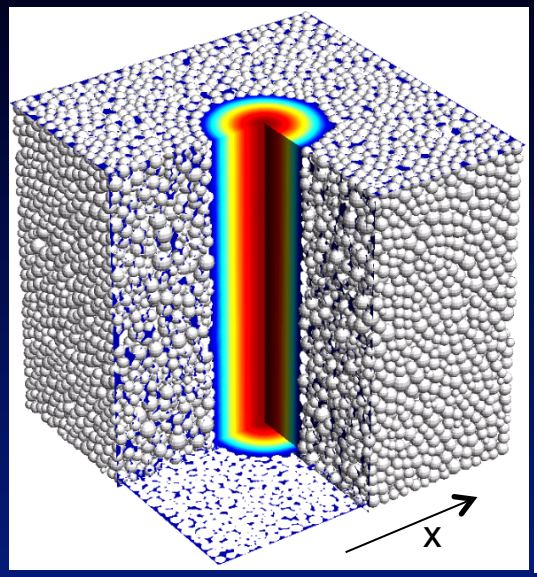
The center tube has the same hydrodynamic behavior as a fracture

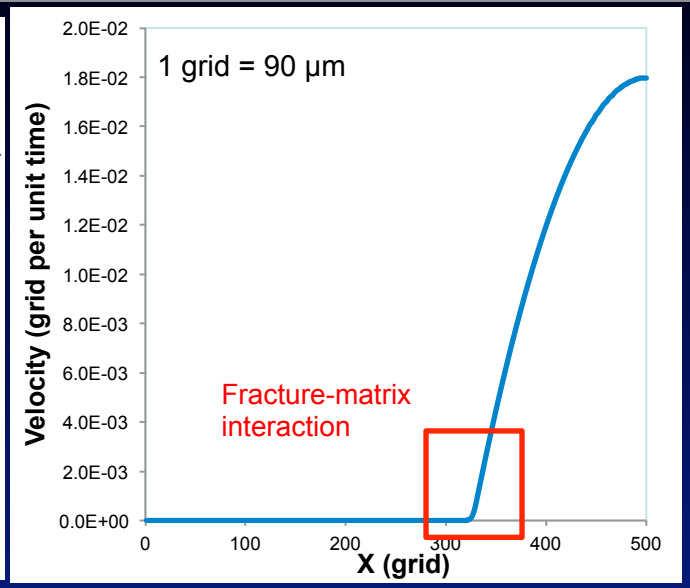
Initial size
Actual: 9x9x9 cm^3, tube diameter = 3 cm
Simulation: 1000X1000X1000, tube =333 grids

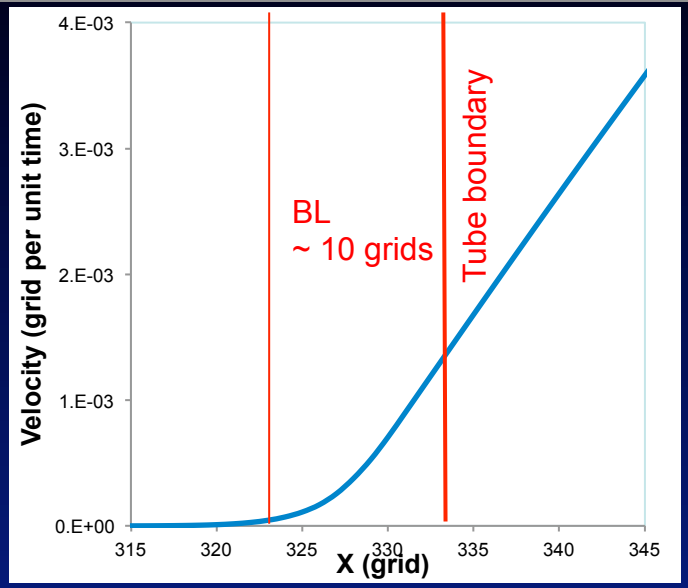
End size:
Simulation: 1000X980X1000 grids

	ϕ	k_x (m^2)	k_y (m^2)	k_y (m^2)
Initial value	0.3290	3.77×10^{-9}	3.77×10^{-9}	2.91×10^{-6}
End value	0.3173	2.88×10^{-9}	2.98×10^{-9}	2.70×10^{-6}

Flow in the "fracture" and flow in the matrix







- Poiseuilles law for laminar flow with non-slip boundary condition in a cylindrical pipe (D = 3 cm, and L = 9 cm)

  Permeability = $D^2/32 * (\pi D^2/4)/L^2$ = **2.45e-6 (m^2)**
- DNS takes into account the slip resulted by fracture-matrix interaction

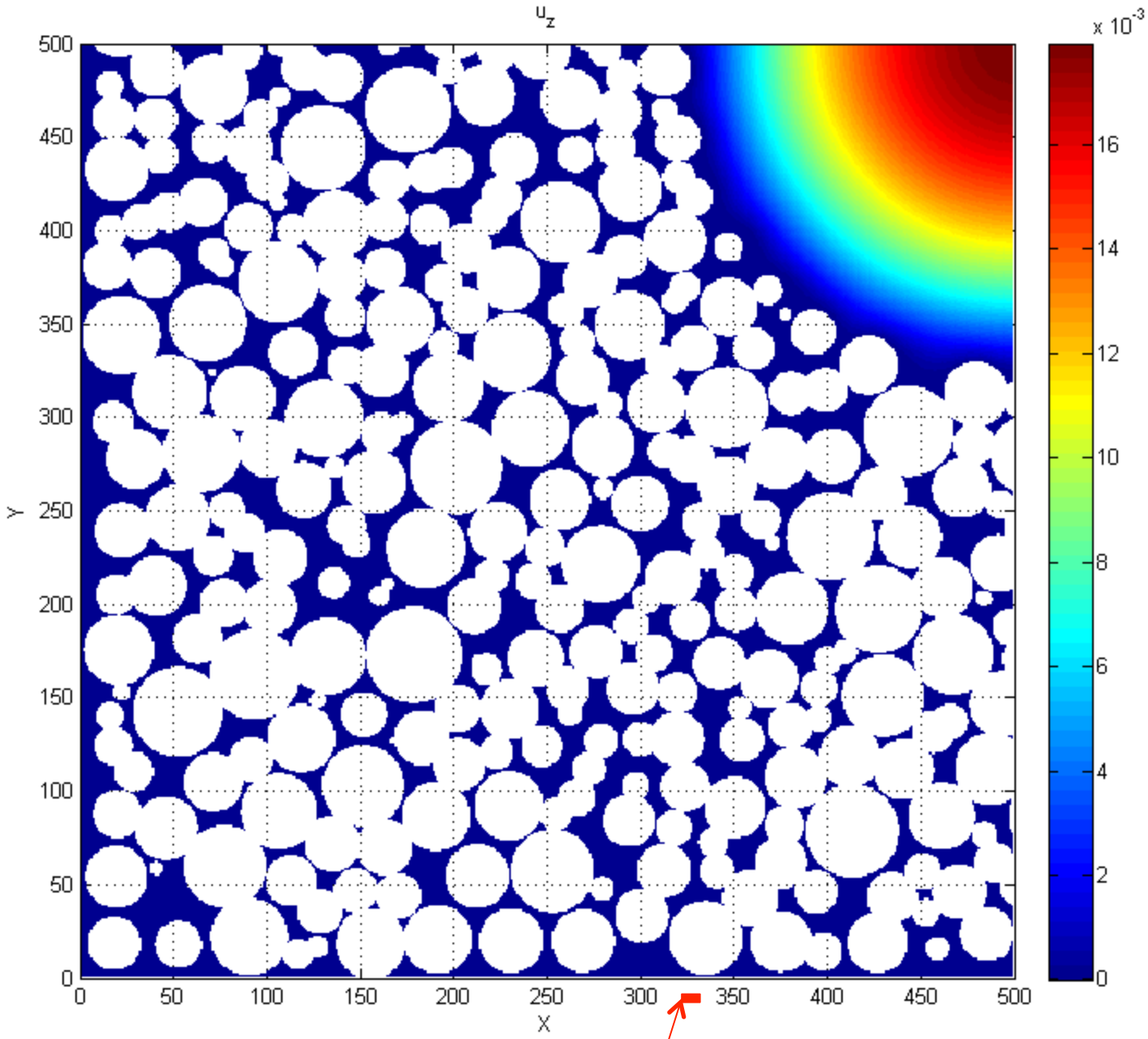
  Permeability = **2.91e-6 (m^2)**

  Increase = 18.8% !
- If assume D* = D+2*BL (D* - effective hole diameter, BL – velocity boundary layer due to slip)

  18.8% increase of permeability corresponds to BL = 15 grids, by Poiseuilles law

  BL = ~ 10, from the velocity profile

  Difference may be attributed to the parabolic velocity profile in Poiseuilles law


u_z
x 10^{-3}
500
450
400
350
300
250
200
150
100
50
0
Y
0
50
100
150
200
250
300
350
400
450
500
X
16
14
12
10
8
6
4
2
0
BL

Conclusions

Conclusions:

- Porous matrix can lead to a velocity slip in the fracture. (1)
- Flow in the fracture generates a velocity boundary layer in the matrix, the thickness of which is comparable to the size of a grain. (2)

Next step:

- Conduct flow simulation in a porous medium with a simple fracture to generate data for modeling the slip / boundary layer.

Acknowledgements:

- Funding by RPSEA
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