Predicting the hydraulic properties of Zbraslav sand, as affected by compaction

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Introduction

- The hydraulic properties of porous media extensively depend on their pore structure as described by the size, arrangement, and connectivity of pores.

- Pore Size Distribution (PSD): Strong influence on both mechanical and transport properties

- Porosimetry Methods:
  - Mercury Intrusion Porosimetry (MIP) → Destructive, Toxic
  - X-ray Micro Computed Tomography (µCT) → High initial setup costs

✓ A recent promising alternative method: Non-Newtonian Fluids → Non-destructive, non-toxic and cheap

- Approaches:
  - Yield Stress Fluids Porosimetry Method (YSM) (A. Rodríguez de Castro et al. (2014) [1])
  - ANA Model (Abou Najm and Atallah (2016) [2])

  → Reasonable agreement with MIP and µCT

✓ Xanthan gum: Common non-Newtonian biopolymer → Shear-thinning fluid

Introduction

- **Temporal changes in the soil hydraulic properties due to compaction can affect a range of near-surface and subsurface flow processes.**
- **Several natural and human-induced processes such as the use of farm machinery in agricultural operations, grazing activities, raindrop impact, timber harvesting in forests, fire, and various geotechnical engineering projects can lead to soil compaction.**
- **Soil compaction alters pore spaces and consequently affects the bulk density, porosity, and soil hydraulic properties.**

Motivation: **Investigation of compaction effects on pore structure, in particular the PSD, and soil hydraulic properties using non-Newtonian (shear-thinning) fluids**

❖ Numerical Investigation → Fluid-Solid Coupling Method

- Solid phase: Discrete Element Method (DEM)
- Fluid phase: Pore-scale Finite Volume (PFV) [3]

→ **The DEM-PFV Coupling Method**

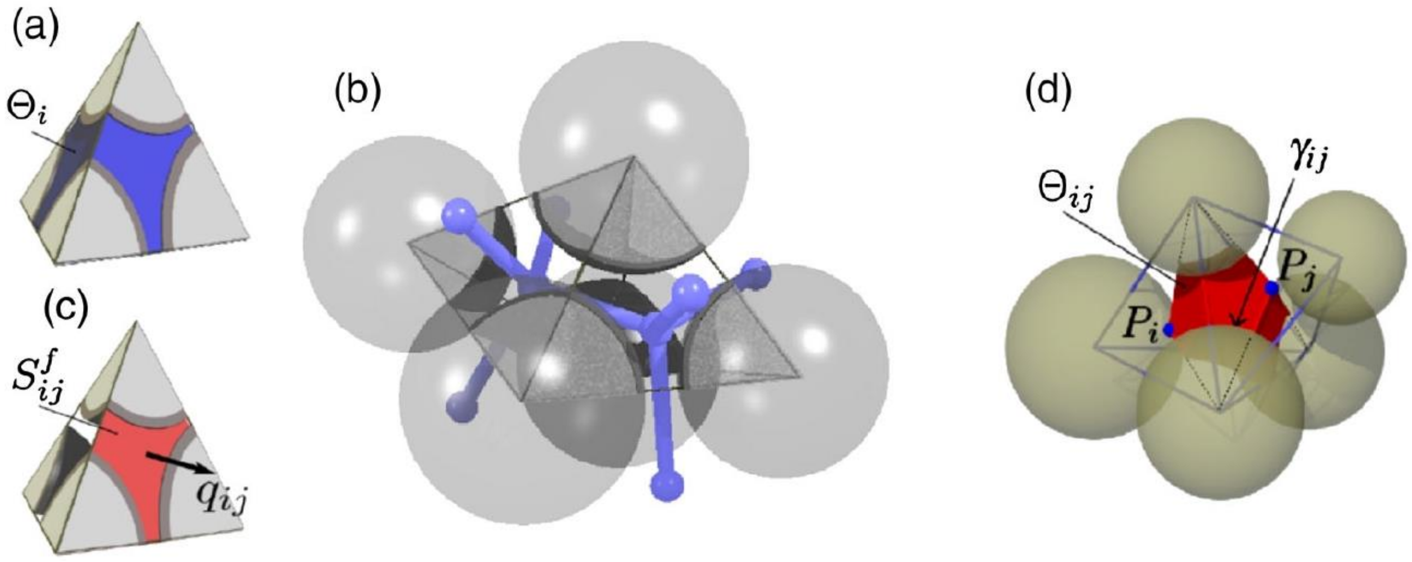

Fig 1. DEM-PFV (a) Volume of fluid in a pore, (b) adjacent pores and local connections, (c) fluid domain of pore contour, and (d) pore partition for hydraulic radius definition [3]

Methods

- **Pore Network Extraction** → **Pore Body and Pore Throat**

✓ **Delaunay Triangulation and Voronoi Diagram**

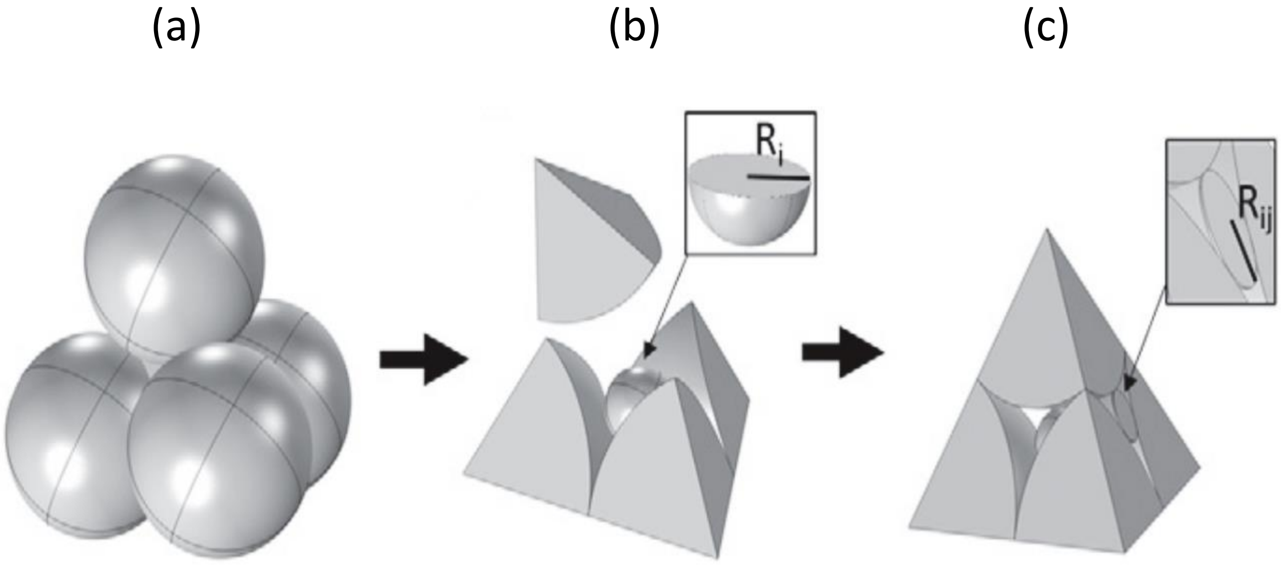

Fig 2. Schematic of the (a) spherical packing with (b) a pore body with radius R_i and (c) a pore throat with radius R_{ij} [4].

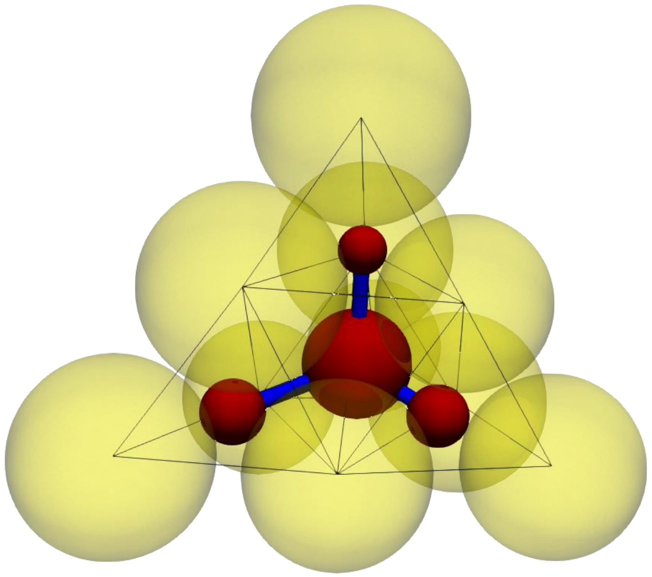

Fig 3. Pore network

Numerical Modeling

- **YADE (Yet Another Dynamic Engine) [5]**
  - ✓ **YADE is a highly extensible open source framework for numerical models using the DEM**
- **The DEM-PFV Coupling Method**
  - ✓ **Fully Saturated media**
- **Compaction:**

First: Triaxial Compaction

Second: Oedometric Compaction

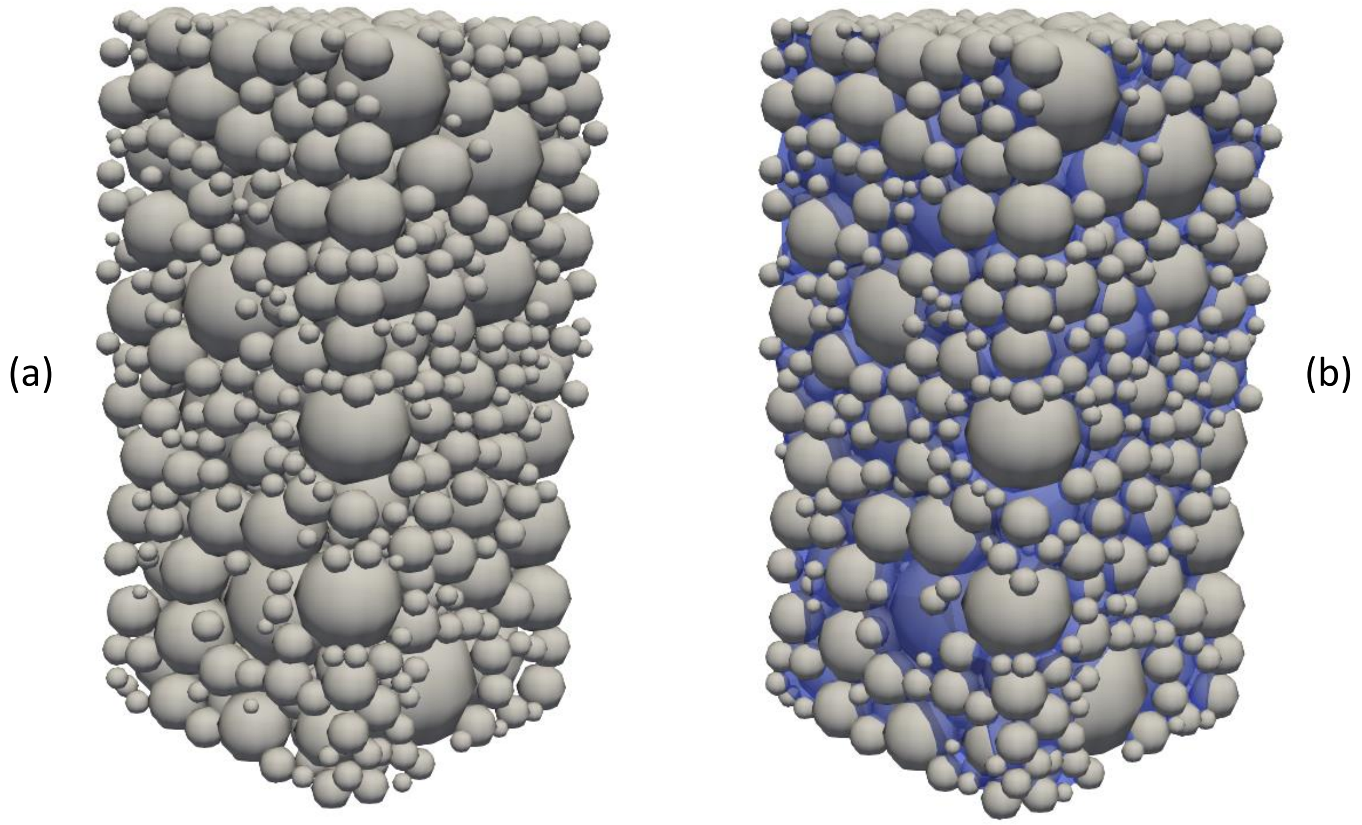

Fig 4. Spherical Packing (a) DEM (b) DEM-PFV

Results

- **Zbraslav Sand** → **Particle size distribution based on J. Feda's experiment data [6]**

✓ **Poorly graded sand**

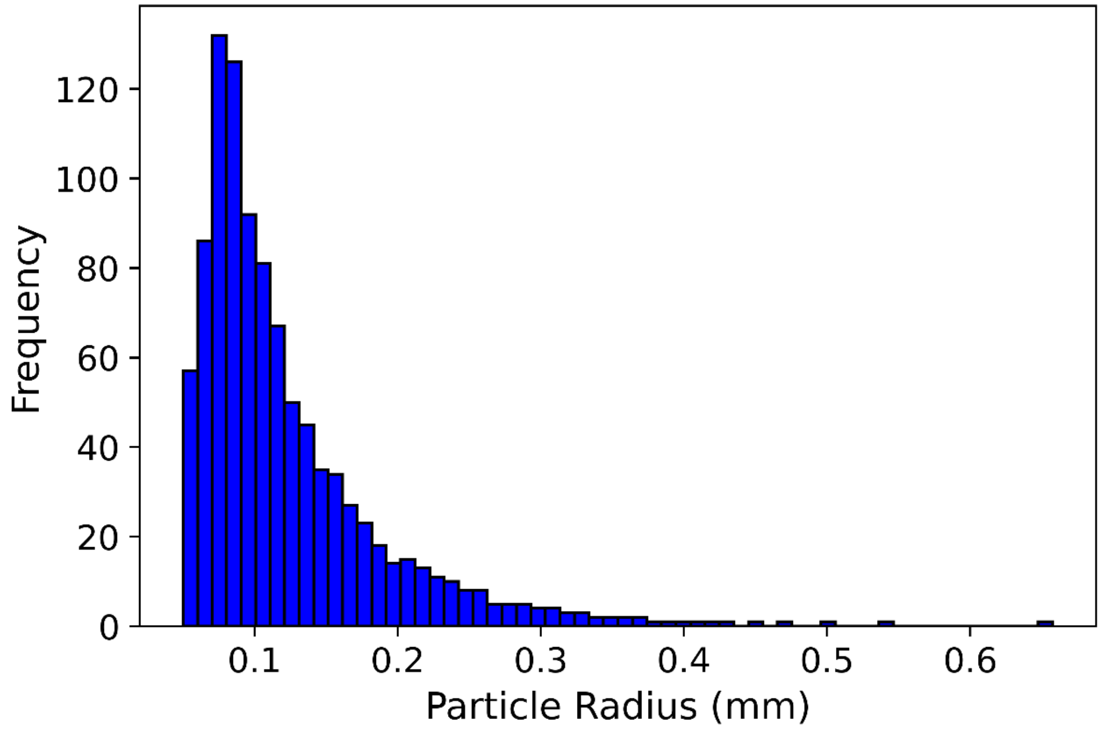

Fig 5. Particle size distribution

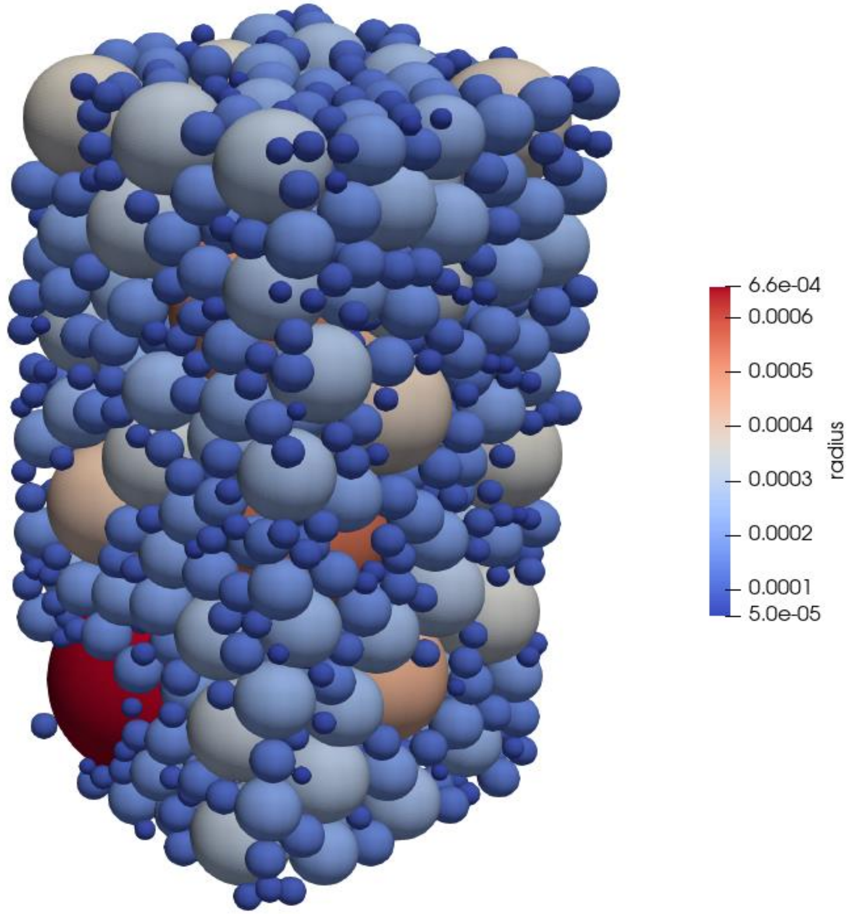

Fig 6. Particle Packing

- **Effect of compaction on pore network**

(a) (b) (c)

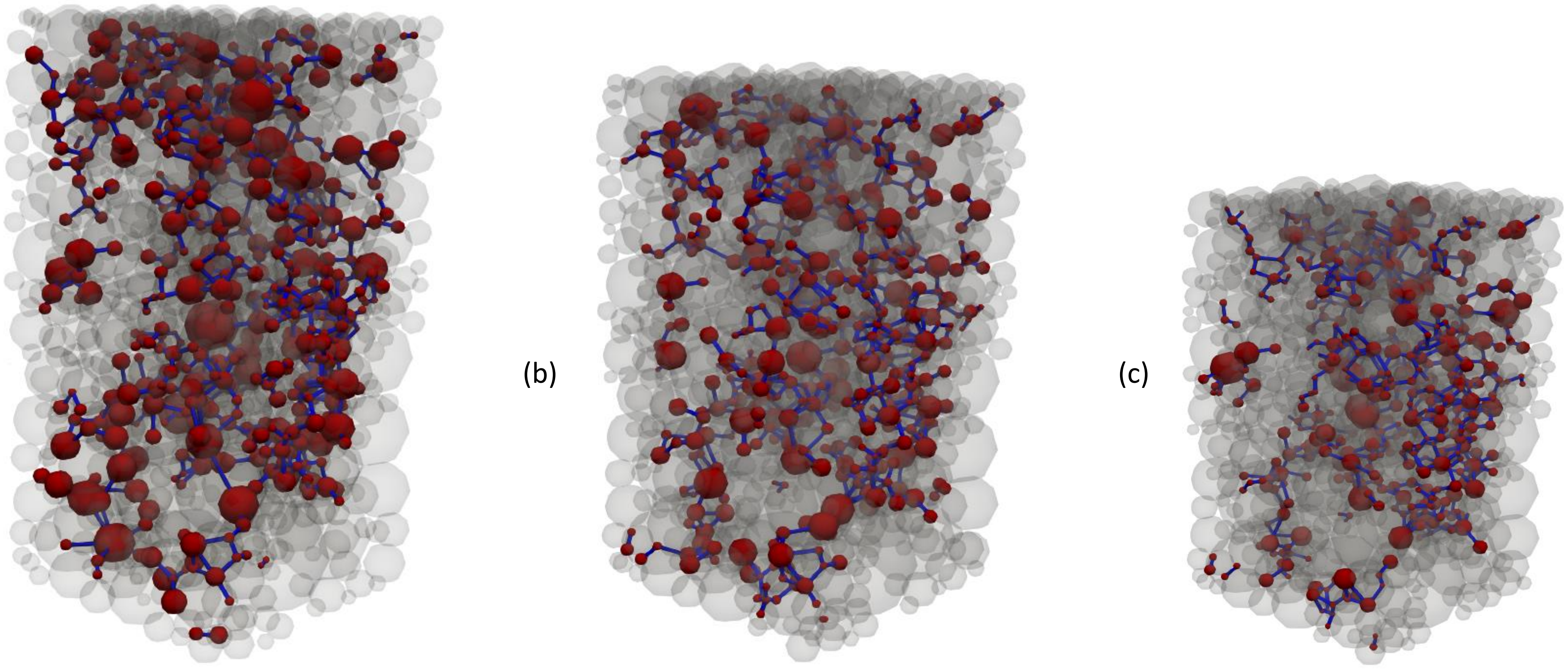

Fig 7. Pore network (a) porosity=0.35 (b) porosity=0.32 (b) porosity=0.29

- **Effect of compaction on Pore Size Distribution**

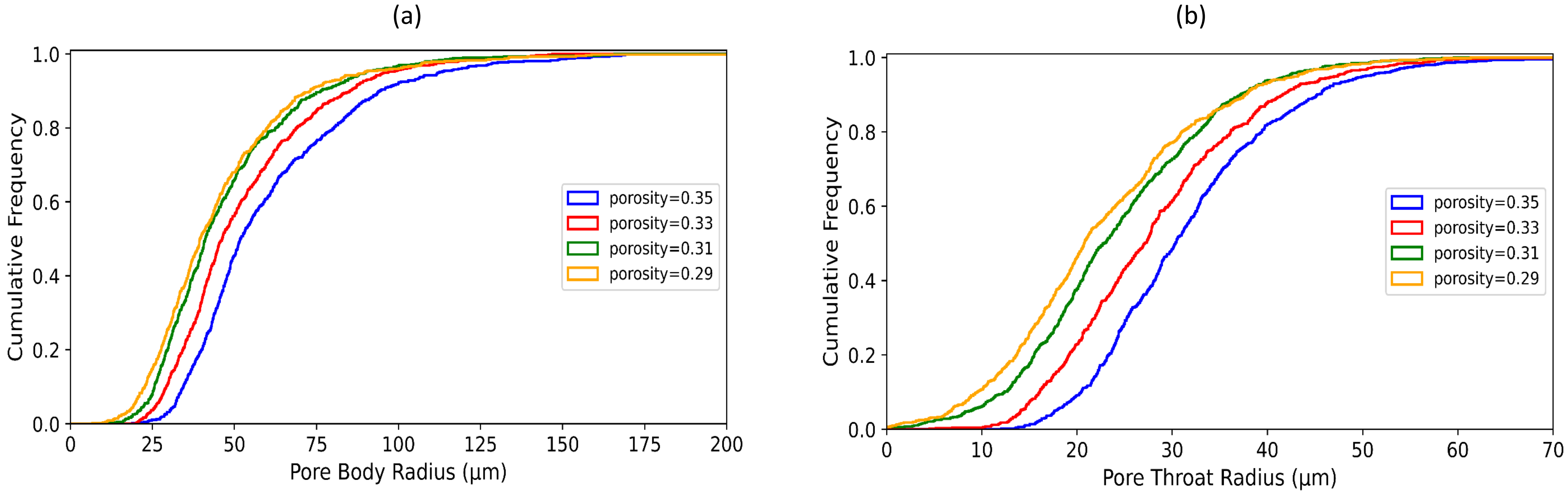

Fig 8. Cumulative (a) pore body and (b) Pore throat radii distributions as affected by soil compaction

- **Effect of compaction on permeability**

(a)

(b)

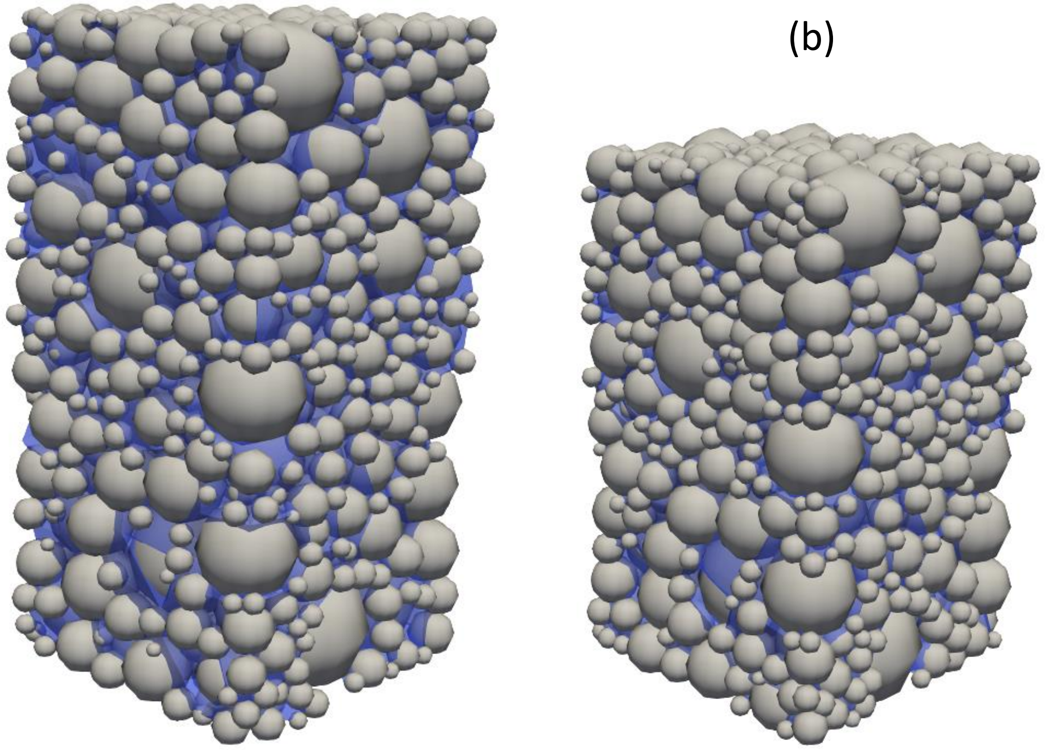

Fig 9. DEM-PFV (a) porosity=0.35 (b) porosity=0.29

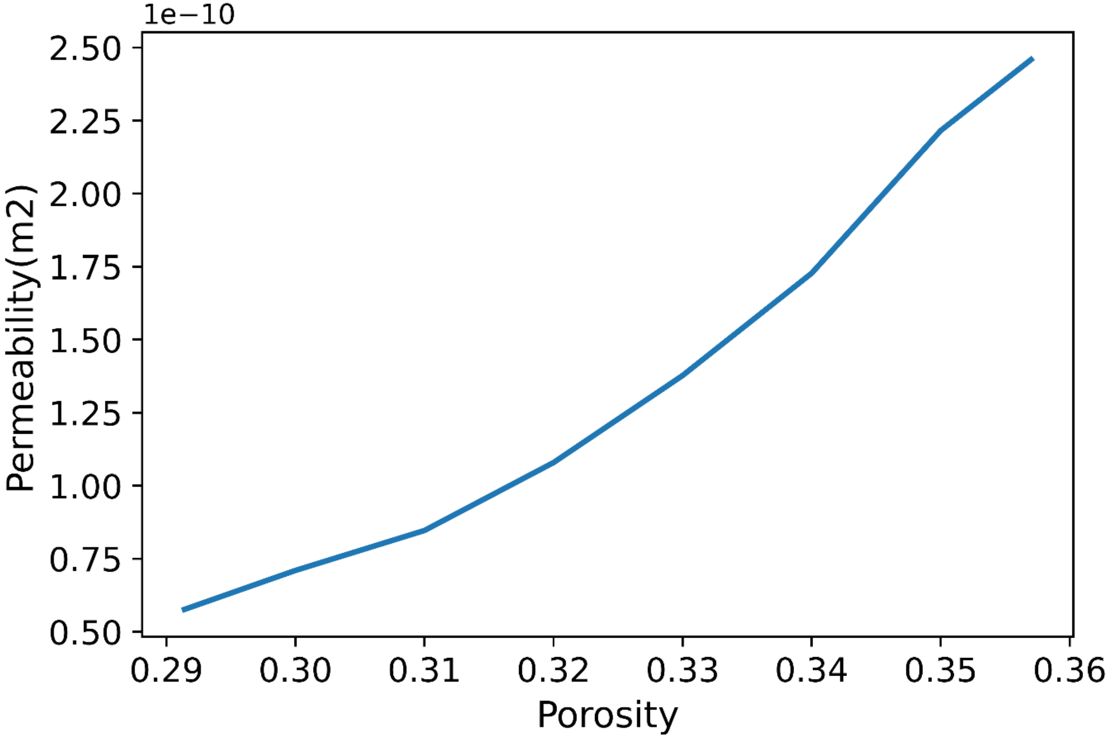

Fig 10. Permeability vs. Porosity

Preliminary Laboratory Experiments

- **Triaxial test**

- **Samples:** Glass beads (to start with)
  - Particle size distribution
  - Compaction Stress

- **Fluids:** Water and xanthan gum solutions
  - Concentration
  - Pressure gradient

- **Permeability** → **PSD**

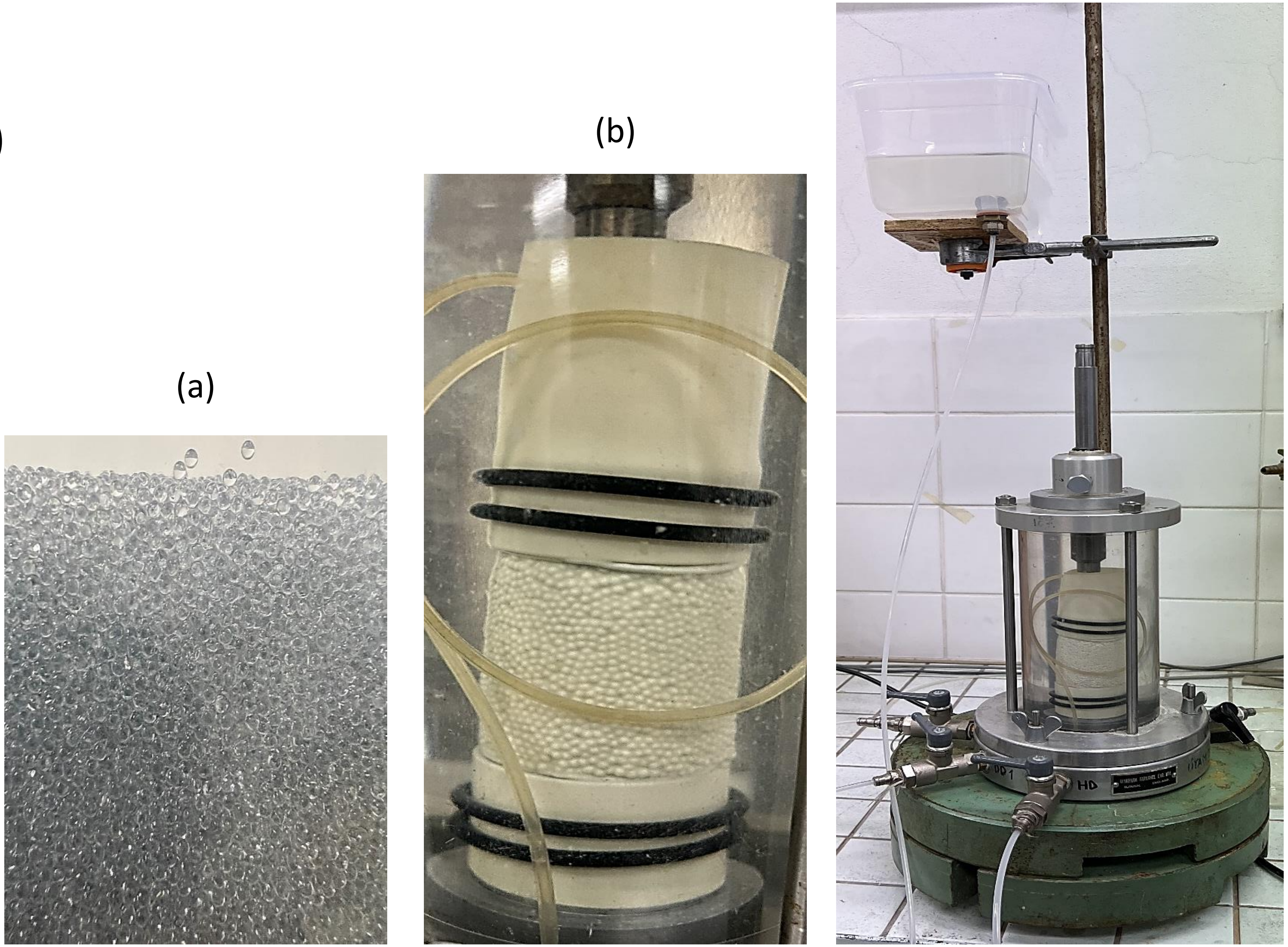

Fig 11. (a) Glass beads (b) Triaxial Chamber (c) Triaxial test system

Discussion

Conclusions:

- **Compaction caused a decrease in the porosity and a uniform change in the pore space.**
- **An increase in the degree of compaction reduced the pore body and throat radii.**
- **An exponential decrease in permeability as a function of porosity following compaction is observed. The results showed that the changes in permeability are consistent with the changes in pore body and throat radii during compaction.**

To be done:

- **Development of the DEM-PFV model for non-Newtonian fluids and real shape particles**
- **Validation of the model with the Pore Network Modeling (PNM) method and the Bundle of Capillary Tubes model**
- **Performing the triaxial test with Zbraslav sand using water and shear-thinning fluids**
- **Performing the MIP and µCT techniques on glass beads and Zbraslav sand**

References

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Thank you so much for your attention

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