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A pore-scale numerical investigation of the effect of pore characteristics on flow properties in soils

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Key words: Pore network modeling; Intrinsic permeability; Flow properties; Pore characteristics

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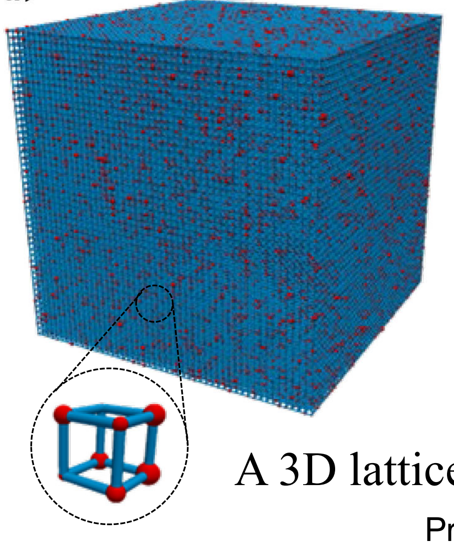
Network calibration and determination

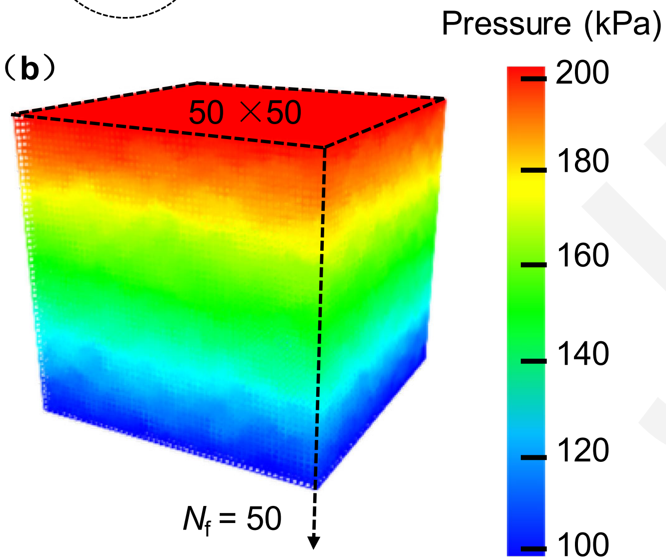
- The 50×50×50 network can save computing time while achieving adequate accuracy for determining the permeability in porous media.

（a）



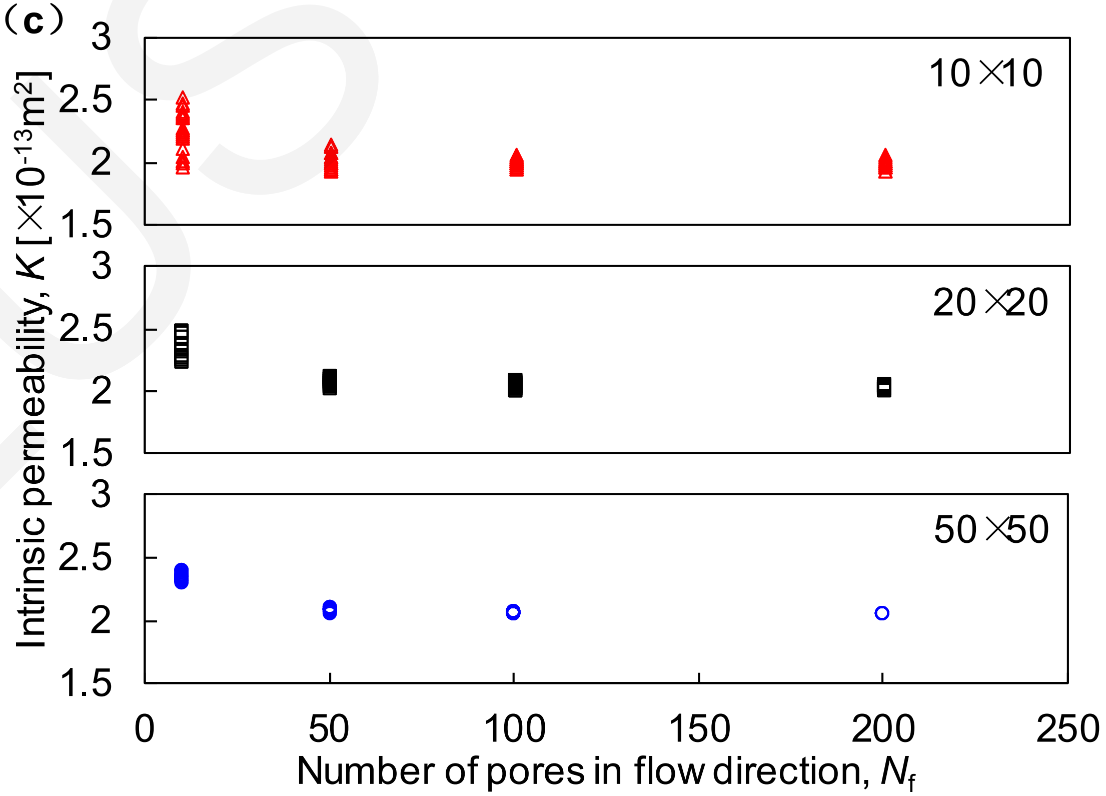
A 3D lattice pore network

（b）



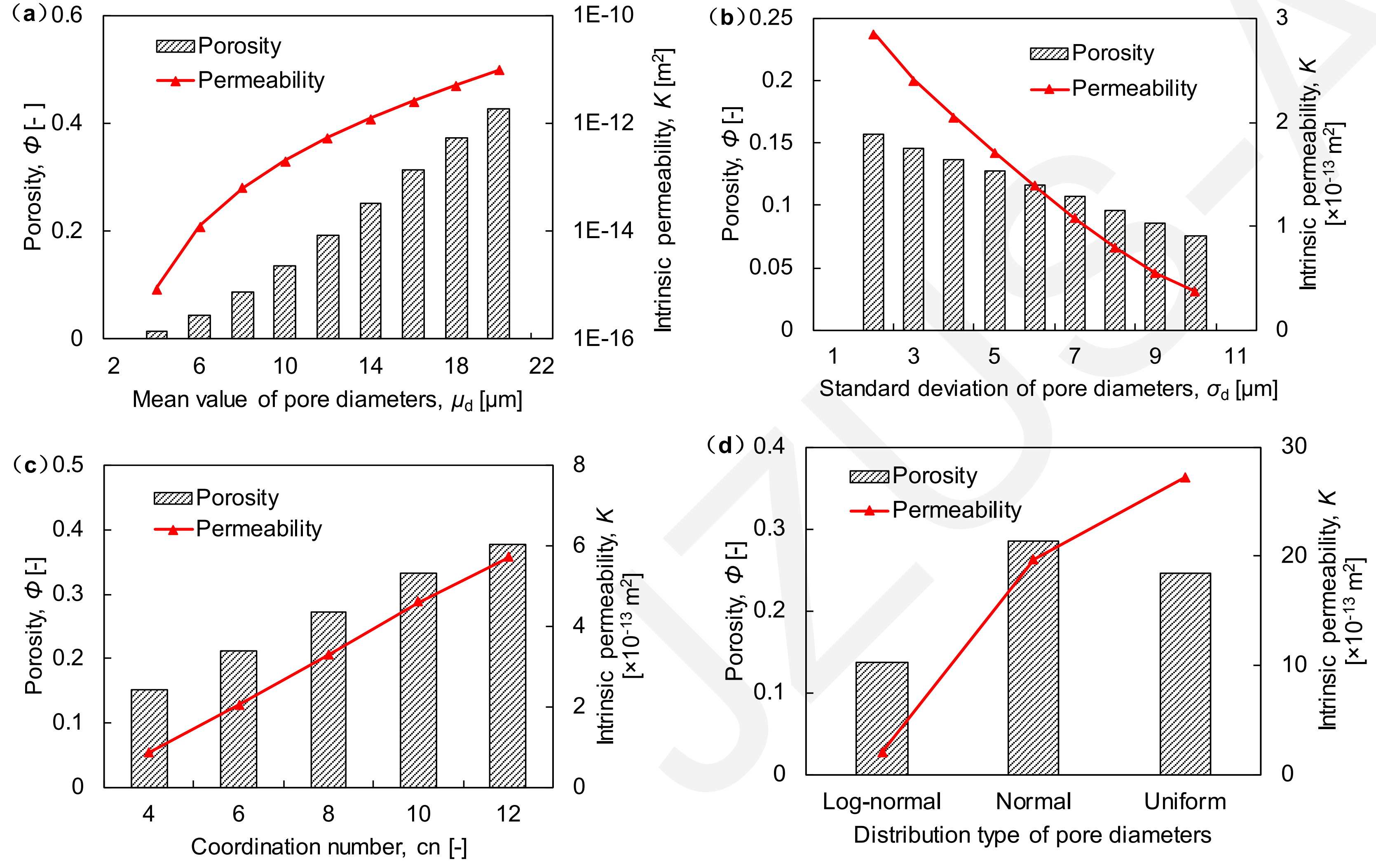
Water pressure distribution

（c）



Computed permeability in networks with different domain sizes

Numerical results——Porosity & Intrinsic permeability



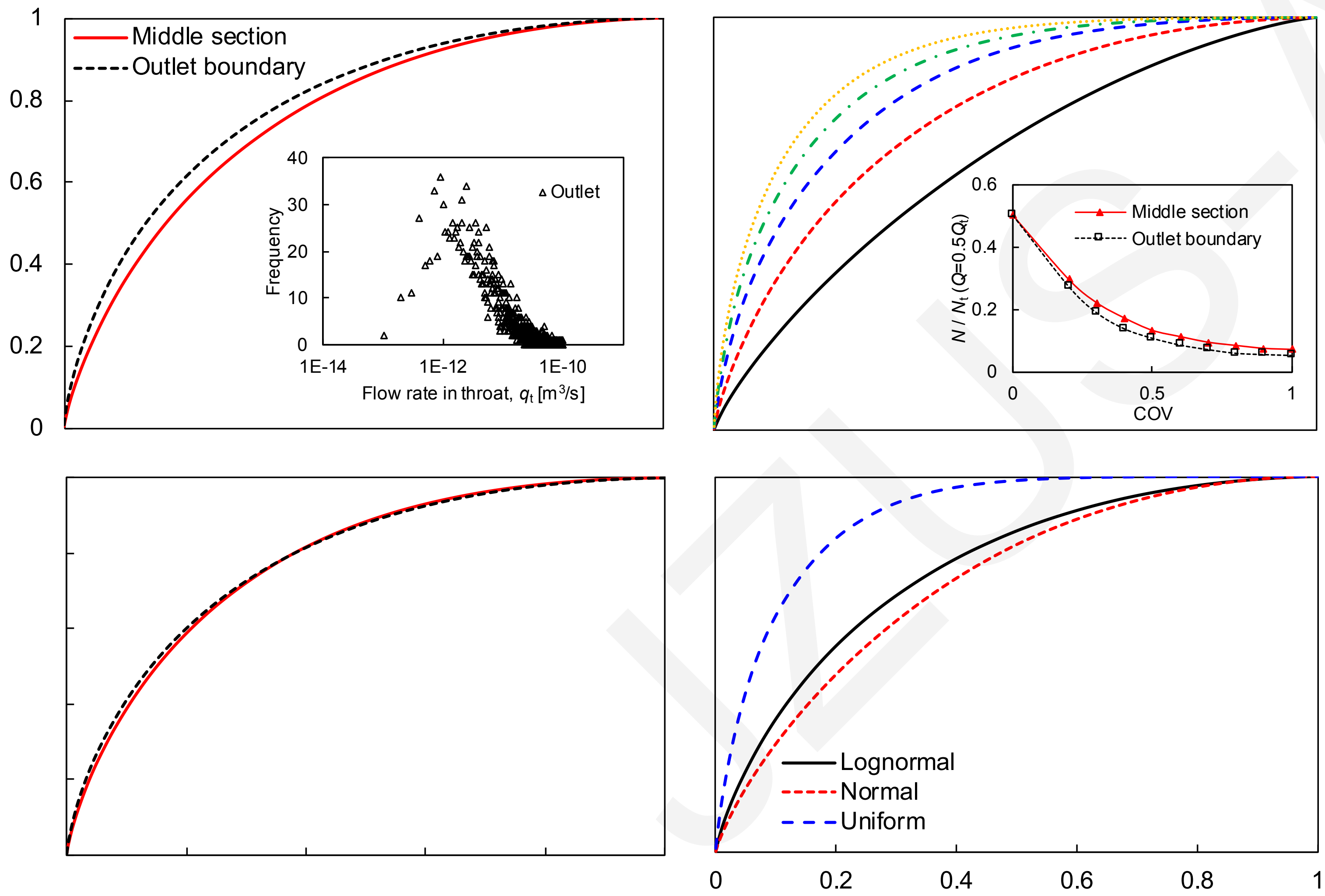
Intrinsic permeability and porosity affected by various pore characteristics

The intrinsic permeability of the whole network K can be determined as:

$$K = \mu \frac{Q}{\Delta P} \frac{L}{A}$$

Interestingly, among the three types of log-normal, normal and uniform PSDs with the same range of pore diameters, the uniform distribution presents intermediate porosity but the largest intrinsic permeability resulted from preferential flows induced by a high degree of heterogeneity in pore sizes.

Numerical results——Flow rate distribution

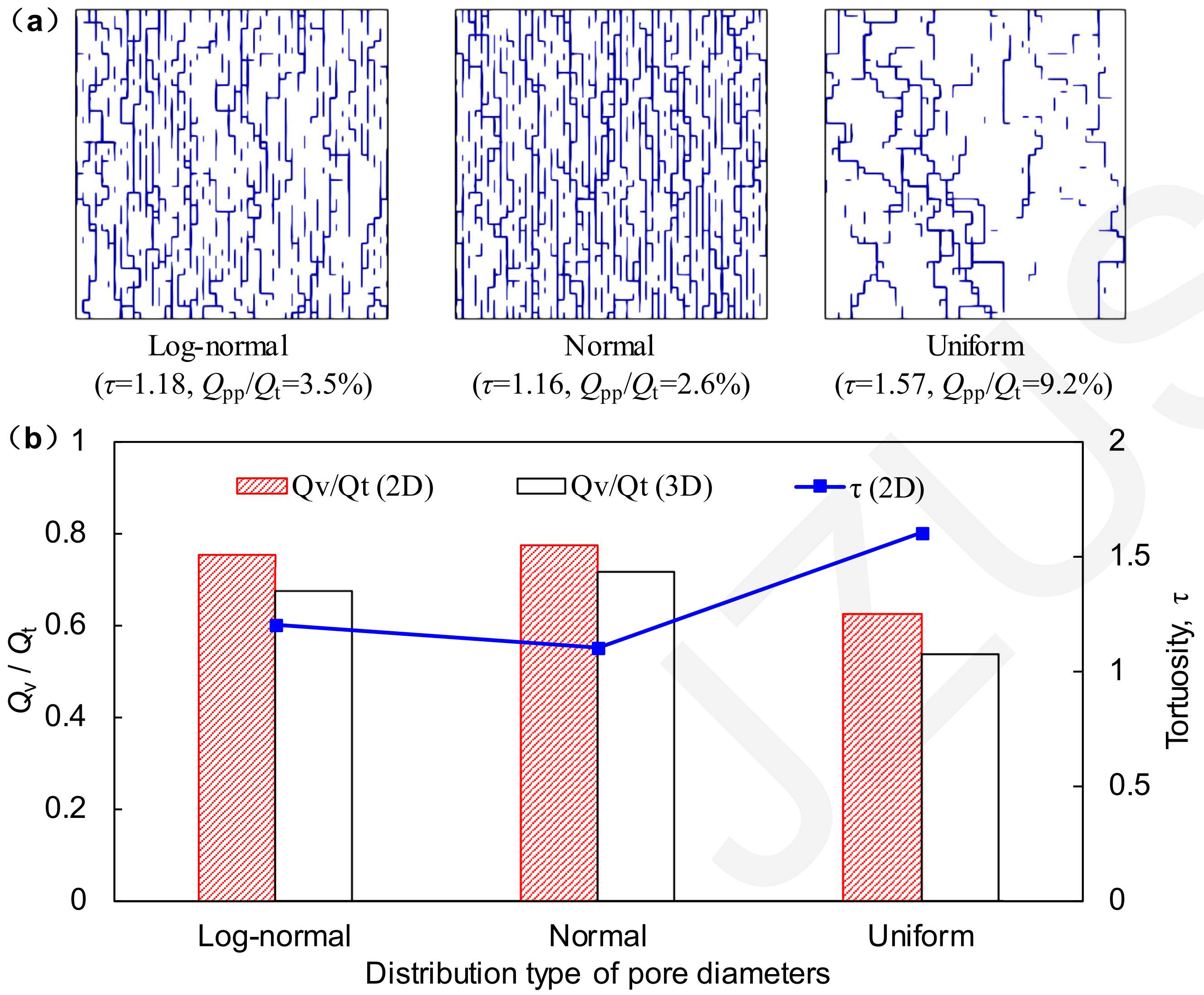


Flow rates in throats at the middle section and the outlet boundary

For the middle section and the outlet boundary of the networks, we add up the flow rate in each throat in descending order of magnitude, and then we can obtain the relationship between the number of throats N and the accumulated flux Q carried by these throats.

The results are presented in a normalized form, i.e., the number of throats N is normalized by the total throat number N_t, and the flux Q is normalized by the total flux Q_t.

Numerical results——Critical flow paths



Critical flow paths affected by the distribution type of pore diameters.

The amount of flux that the percolation path carries Q_{pp} can be approximately determined by multiplying the flux carried by all the visible throats by a number factor, which is defined as the number of the throats in the percolation path over the total number of the visible throats.

The tortuosity τ is defined as the ratio between the total number of throats in the backbone of the percolation path and the number of throats in a straight streamline parallel to the flow direction.

Conclusions

- The porosity and the intrinsic permeability in soils increase with increasing mean pore diameter, decreasing standard deviation, and linearly with increasing coordination number.
- Non-uniform flow rate distribution is more likely to occur in porous media with a larger COV. With the increase of COV, fewer throats are needed to transport half the total flux in the middle section and at the outlet boundary of the network.
- In the network with a higher coordination number, the water pressure at each pore can be balanced by more throats. This mitigates the pressure localization and produces a more uniform water pressure field but slightly increases the chance of non-uniform flow rate field.
- The uniformly distributed pore diameters induces more pronounced preferential flows and the percolation path performs as a dominant path that can carry as much as 9.2% of the total flux. Horizontal throats begin to carry more flux in porous media with higher heterogeneity of pore sizes.