Proppant Transport in Coal Seams: Migration, Segregation, Screen-Out and Embedment

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Introduction

Hydraulic fracturing is used to increase the stimulated reservoir volume in low-permeability coals. Small proppant (e.g. 100-mesh and micron-scale particles) have been used or proposed to access cleats remote from the primary fracture. This raises a number of questions related to implementation which are difficult to answer with downhole observations or experiments:

- What is the carrying capacity of a fracture or cleat?
- What drives clogging and screen-out of proppant?
- What permeability is retained after fracture closure?
- How does vertical and horizontal transport differ?
- How do particles 'leak-off' into or occlude cleats?

This research has developed and applied high-fidelity computational models of fluid-solid-particle interactions relevant to proppant transport in coals. The models are based on the lattice Boltzmann (fluid), discrete element (particles), and finite element (coal) methods, and deployed on high-performance computers.

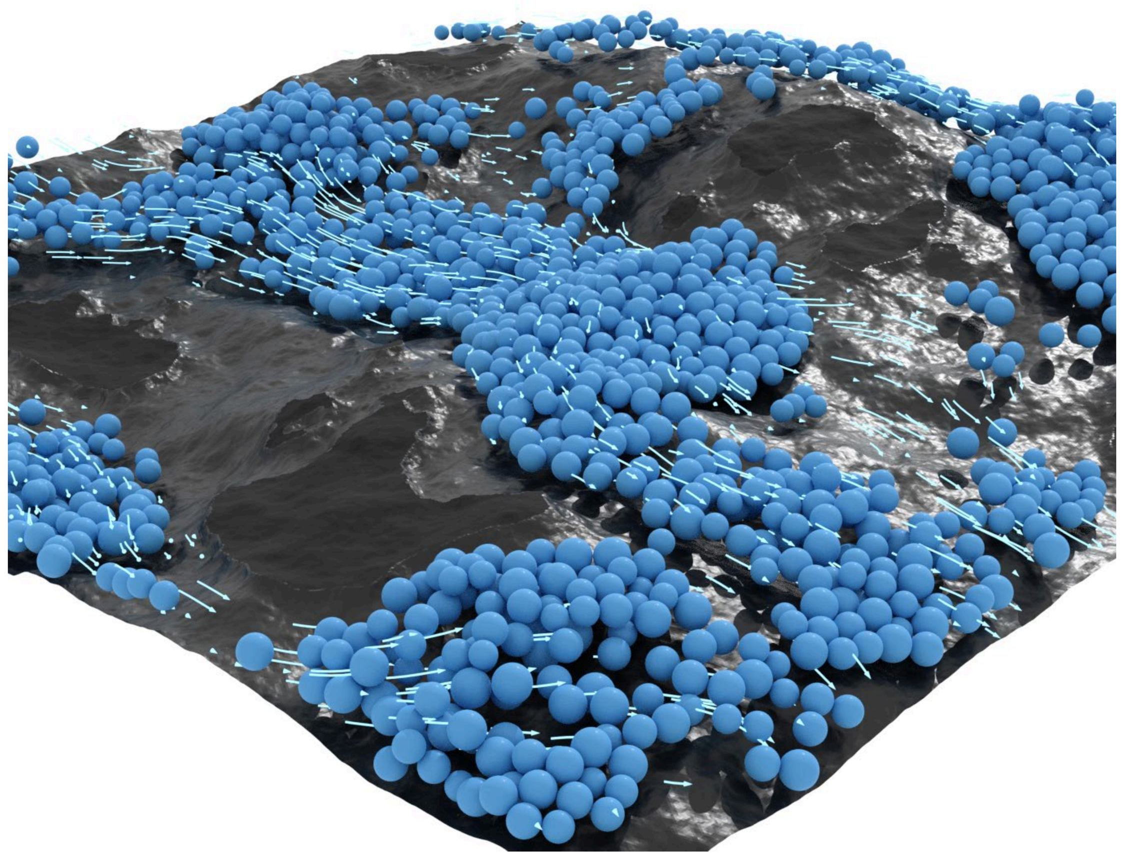
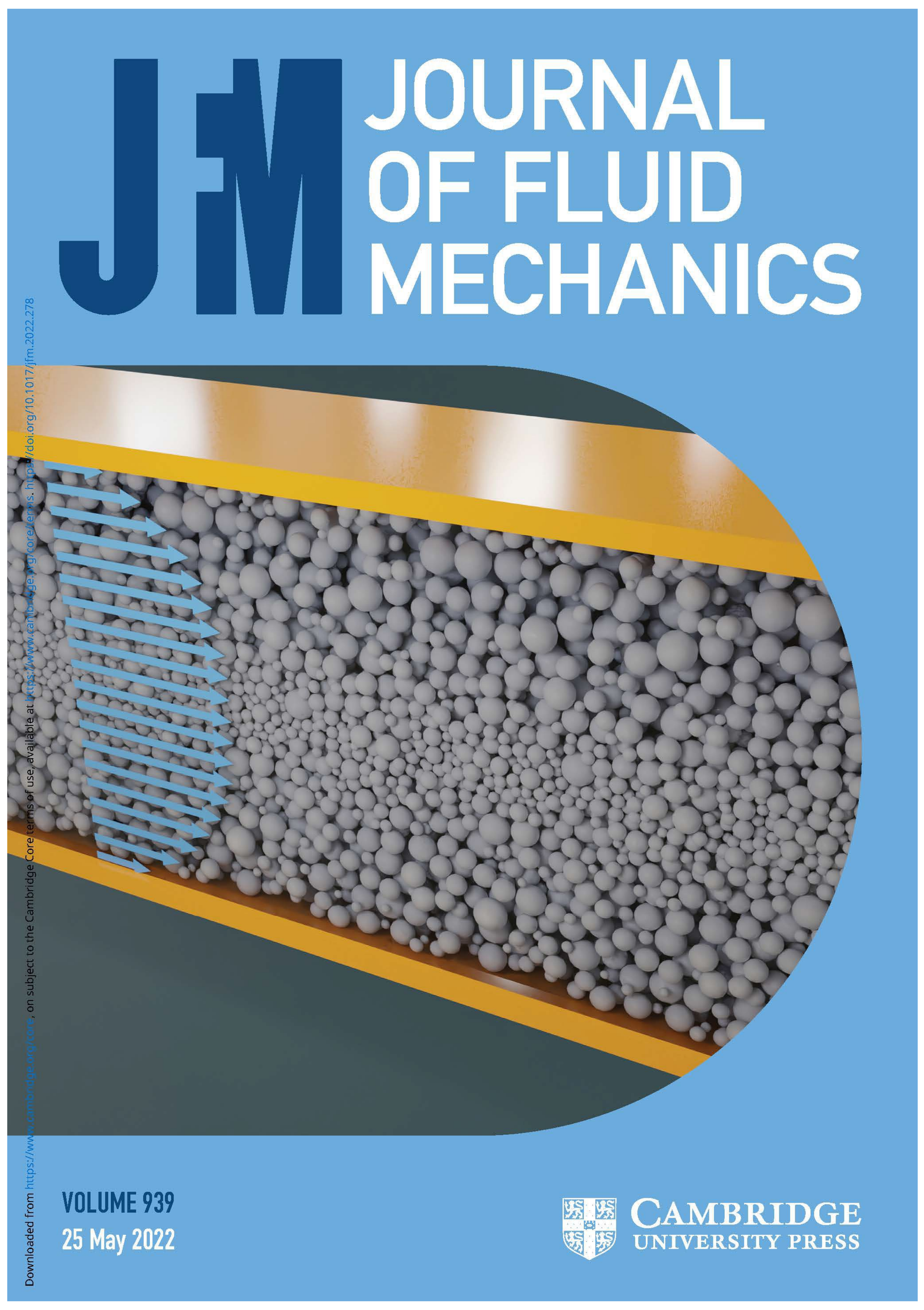


Figure 1: Rendered image of proppant transport in a synthetic coal cleat, as modelled using the lattice Boltzmann method (LBM) and discrete element method (DEM). The simulation framework includes non-Newtonian rheology and DLVO forces.



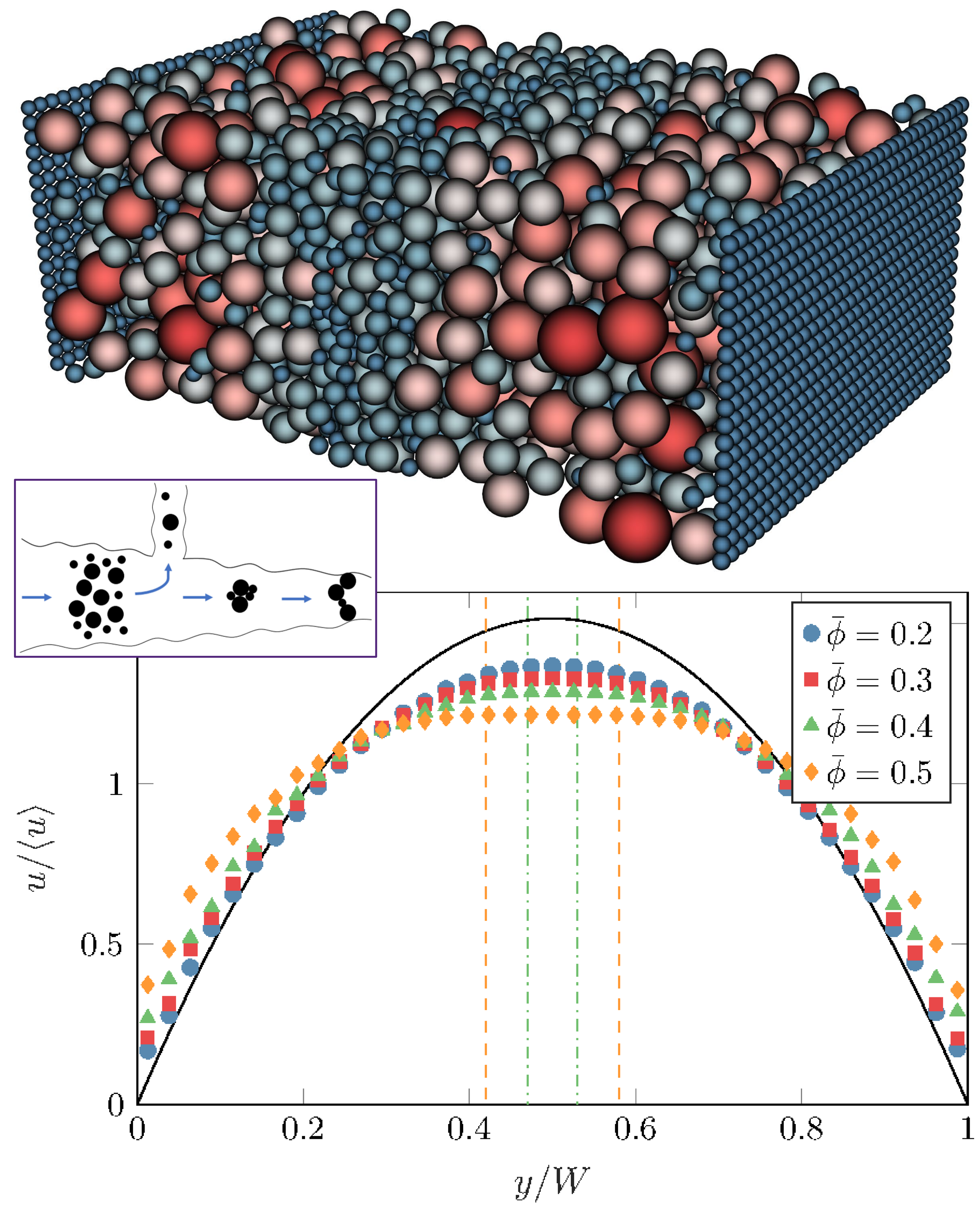


Figure 3: Results of fully-resolved simulation of polydisperse proppant transport in a channel under constant pressure gradient, showing the smallest particles forming a plug in the centre of the channel when the solid volume fraction exceeds 0.4. This has implications for injection sequencing where tight size control is not possible or available (i.e. due to cost) and the smallest particles are intended for cleat stimulation or blockage (see inset). Further details in Di Vaira et al. (2022) Influence of particle polydispersity on bulk migration and size segregation in channel flows. *Journal of Fluid Mechanics*, 939: A30 doi:10.1017/jfm.2022.166

Results

Elastoplastic proppant embedment and retained fracture permeability

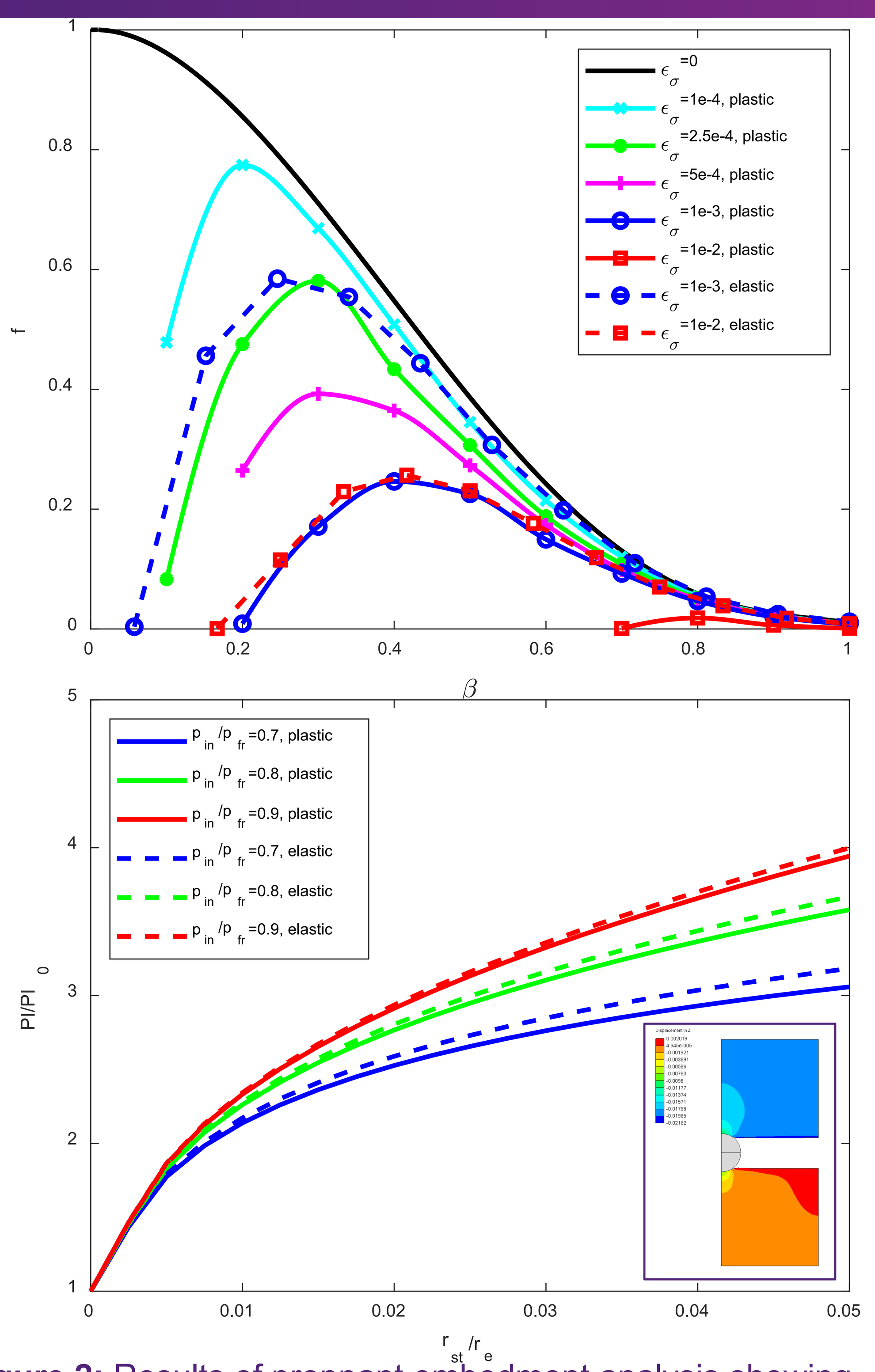


Figure 2: Results of proppant embedment analysis showing (above) retained fracture permeability factor, *f*, as a function of monolayer pack spacing, *β*, with and without (inset) elastoplastic coal deformation, and (below) the resultant productivity index, *PI*.

Probabilistic analysis of proppant clogging (with electrostatic forces)

Proppant screen-out is a function of fracture width and texture, proppant volume fraction, and transport behaviour (e.g. wall-particle collisions). It is generally not a deterministic process. Many realisations of high-fidelity simulations have shed light on this phenomenon

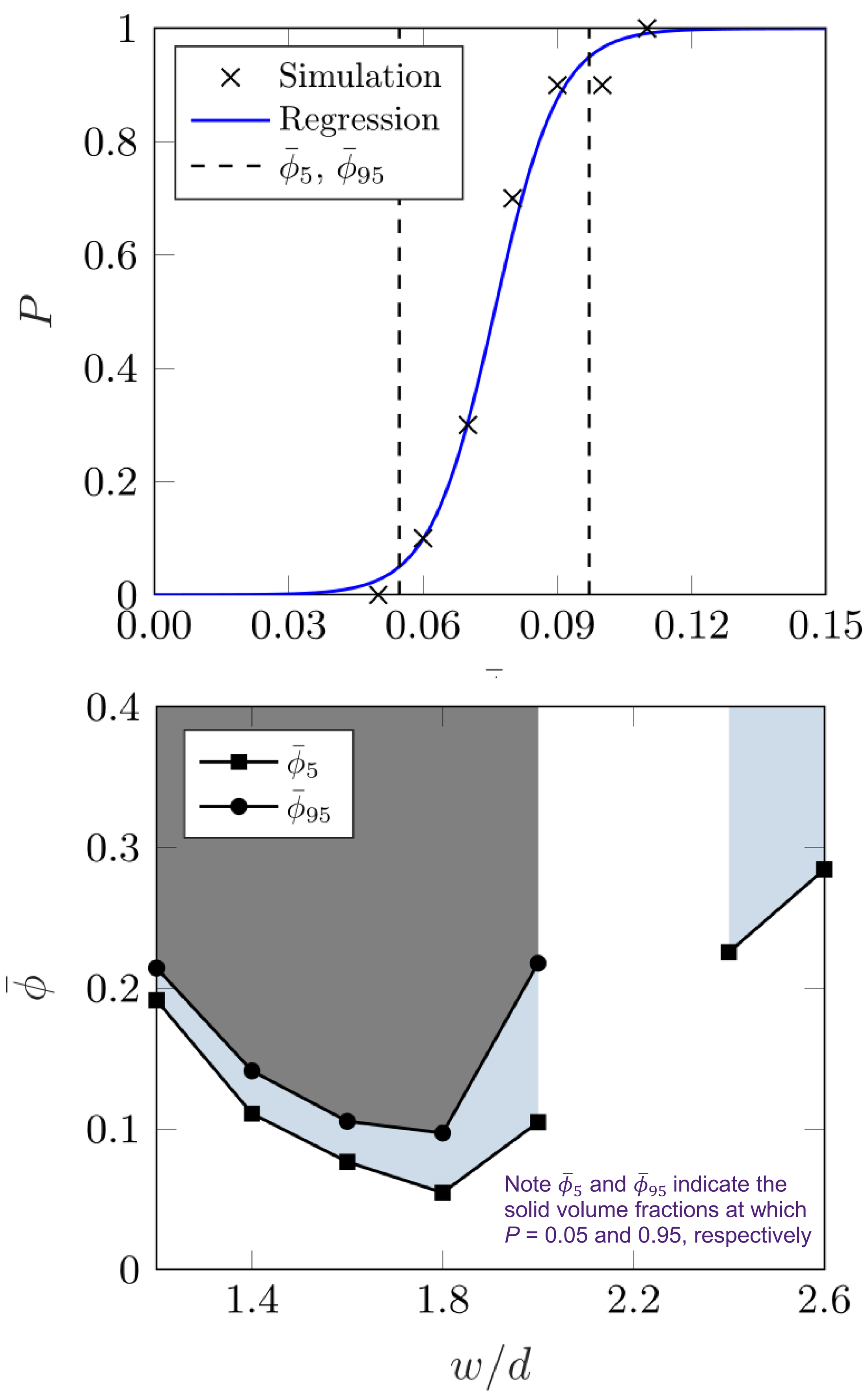


Figure 4: Results of proppant clogging analysis showing (above) a discrete set of clogging probabilities obtained via simulations and fitted with a predictive regression model (*w/d* = 1.8, *St* = 0.1), and (below) the dependence of clogging on the non-dimensional channel width, *w/d*.

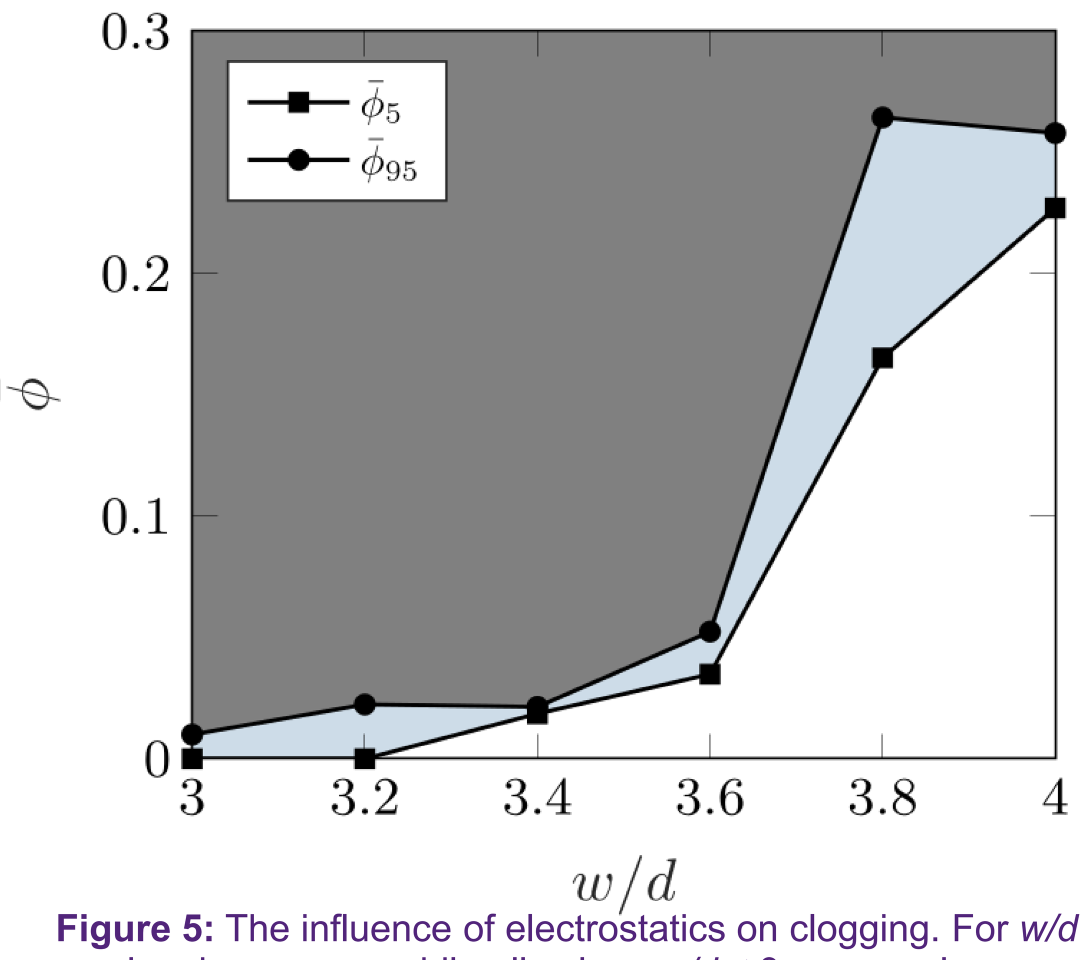


Figure 5: The influence of electrostatics on clogging. For *w/d* > 4 no clogging occurs, while all values *w/d* ≤ 3 are equal.

Interrogating STIM-LAB data on leak-off and fracture occlusion

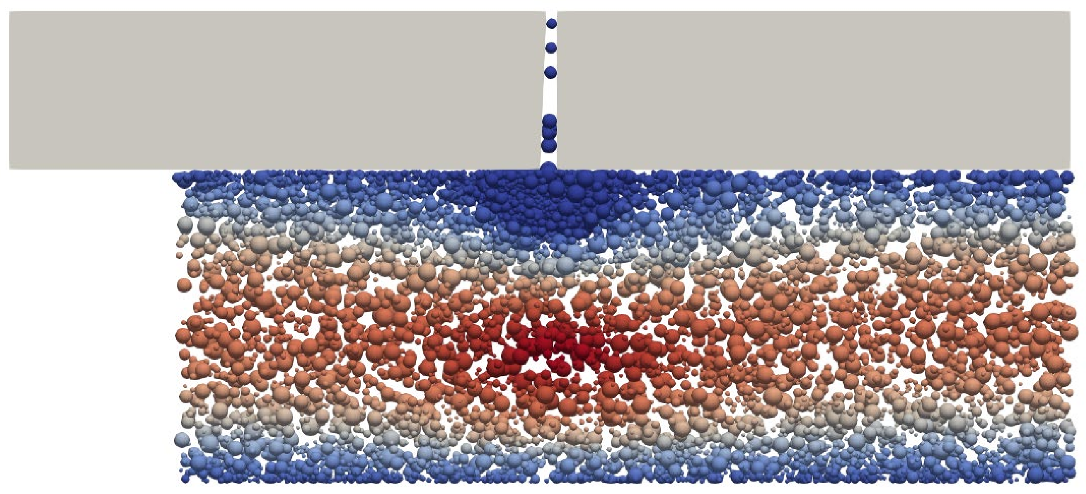


Figure 5: The formation of a proppant mound at the entrance to a 160µm cleat when a combination of 100 and 625 mesh is carried by a Newtonian fluid. The use of a shear-thinning fluid results in a smaller mound due to greater flow resistance (and therefore pressure drop) through the mound.

Conclusions

High-fidelity simulations of proppant behaviour in hydraulic fractures have generated fundamental new understanding in a number of areas. Next steps are to:

1. Incorporate more realistic fracture texture/tortuosity;
2. Explore the influence of non-Newtonian rheology;
3. Translate upscaled results or surrogate models to industry-relevant simulators.

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