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New modeling approach for optimized proppant placement

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Why do we care about perforating strategy?

Why

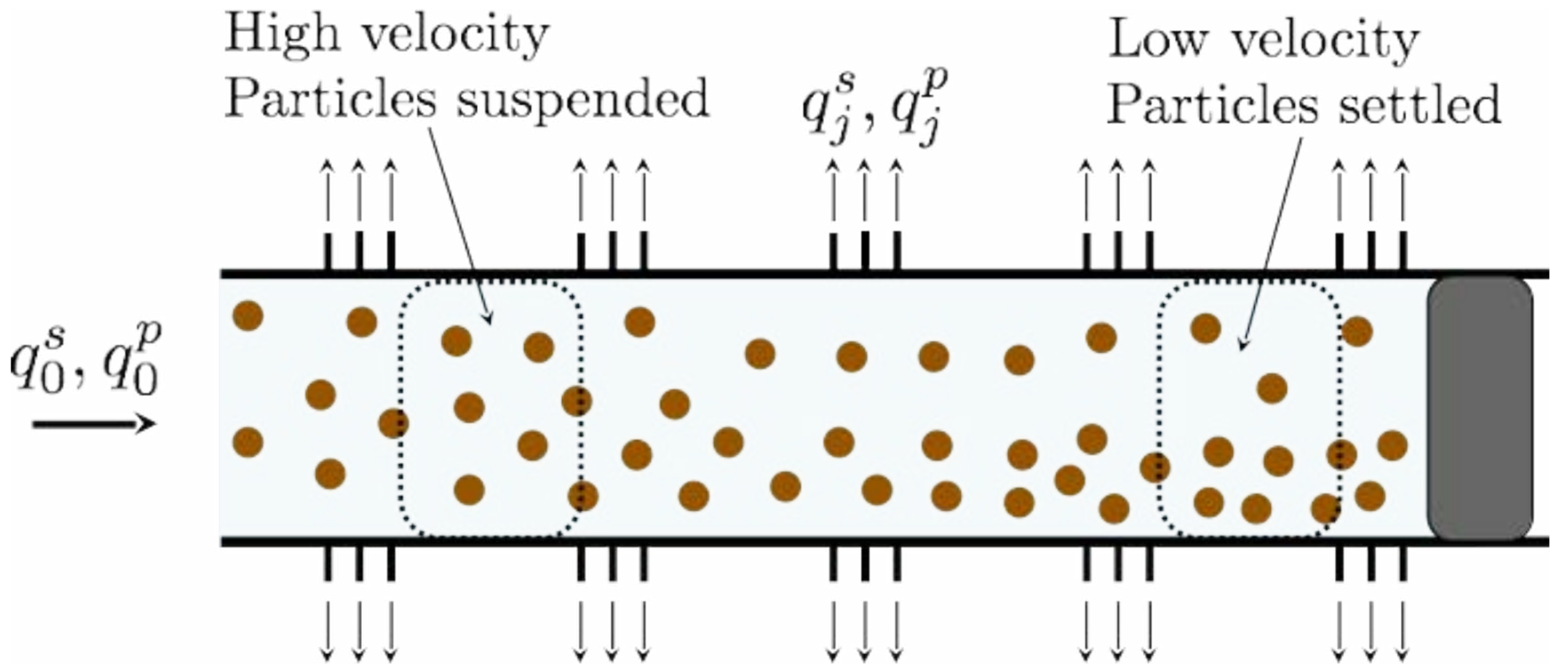
- Improving your perforation strategy is an ‘easy win’ for adding value across your asset.
- Perforation strategy changes to uniformity can be measured with high fidelity and in a cost-effective way.
- Improvements in uniformity translate directly into production.
- Increasing UI from 0.5 to 0.75 is worth approximately $500k per well (Cipolla et al. 2024).
- Increasing UI from 0.75 to 0.9 is worth an additional $500k per well (Cipolla et al. 2024).

How

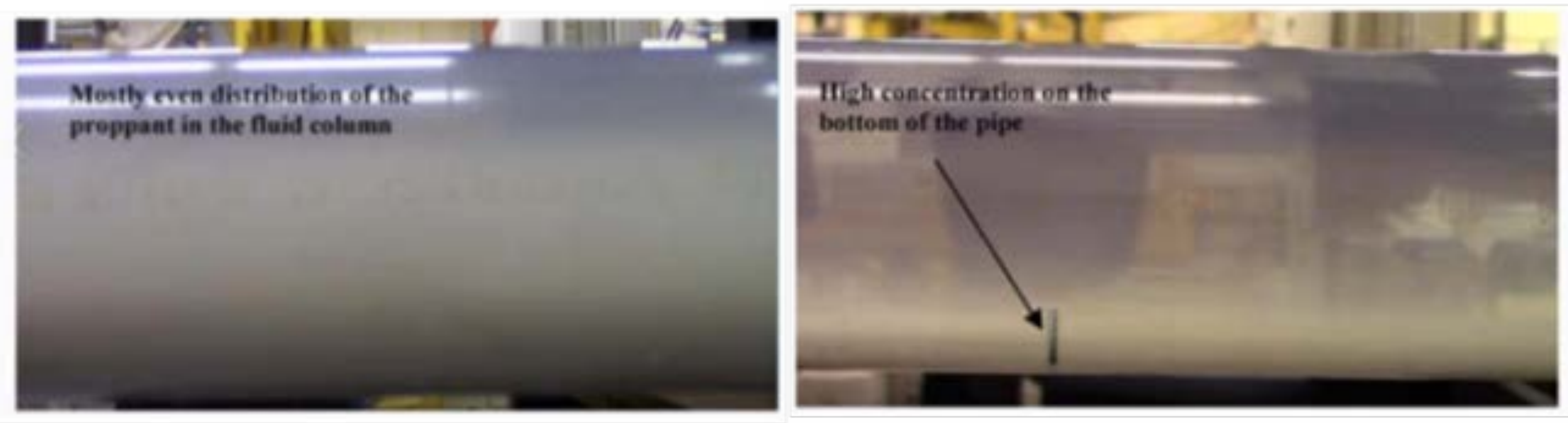
- Fast-running model that includes the key physics that control fluid and proppant transport from the wellbore.
- Allows to validate the model and iterate to quickly optimize stage design.
- Monte Carlo uncertainty quantification and optimization.
- There is variability between datasets (ie, some have much more erosion than others). As a result, there is not one single ‘correct design’, and you need to measure and optimize.

Proppant transport in the wellbore

Problem 1: Proppant settling

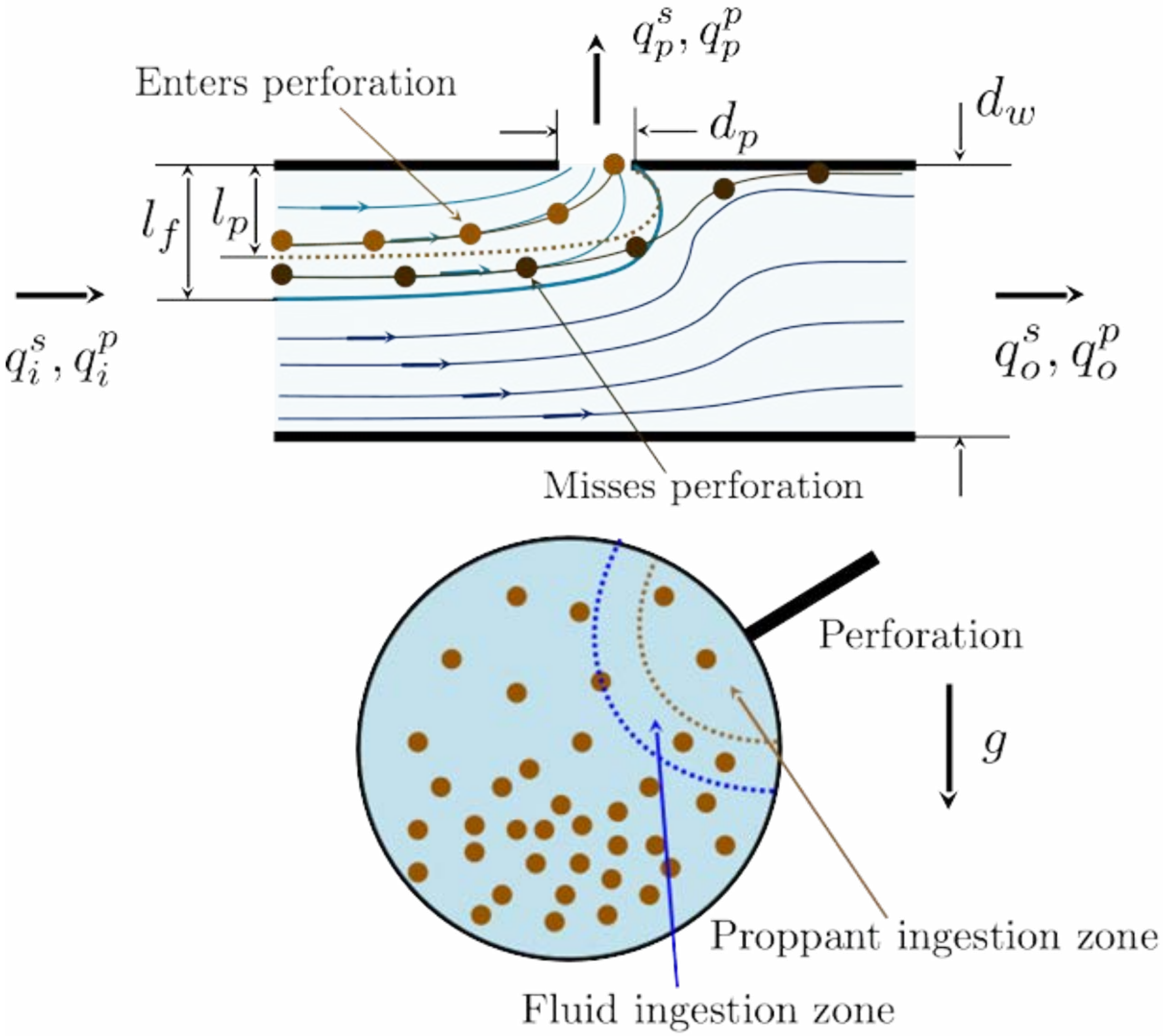


- Flow rate decreases along the stage
- The ability to suspend particles decreases
- Perforation phasing becomes crucial once particles accumulate at the bottom



Ahmad et al., 2019

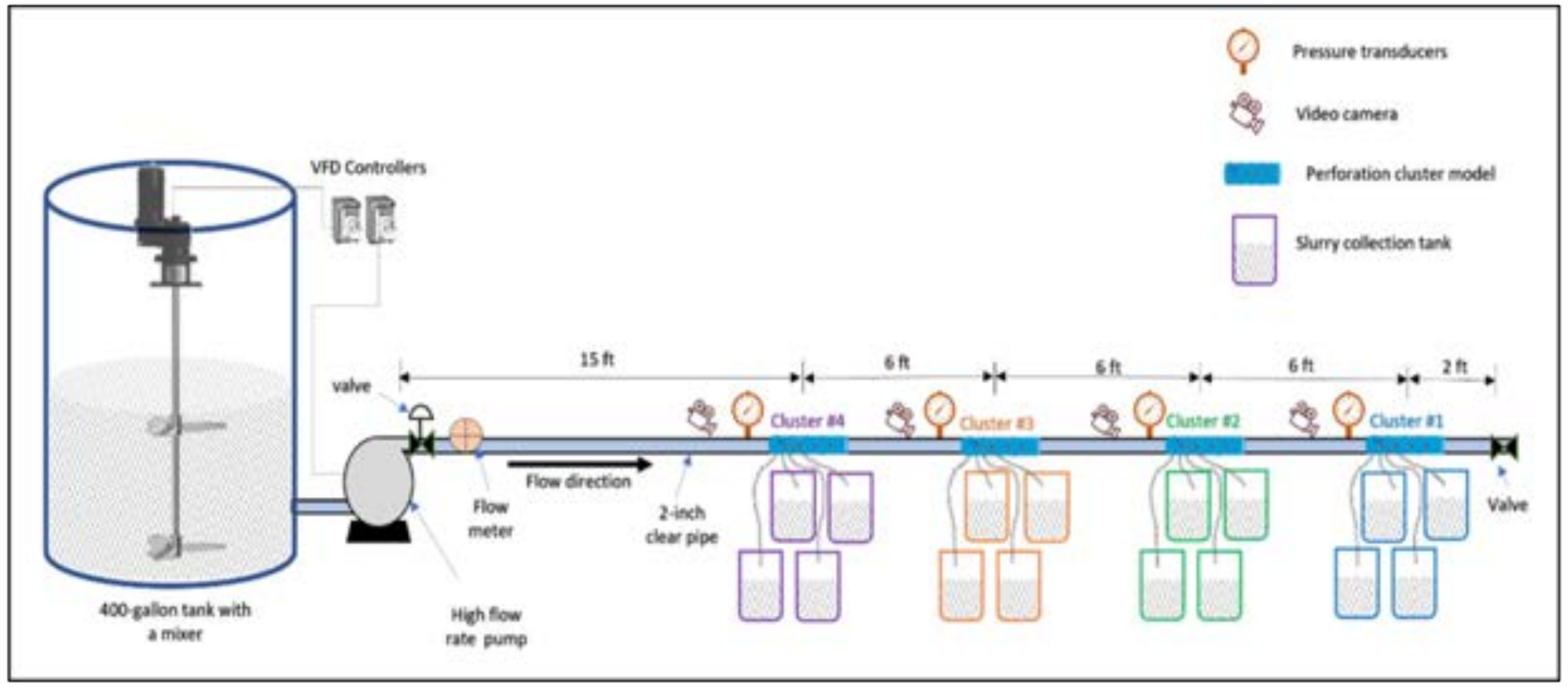
Problem 2: Particle inertia



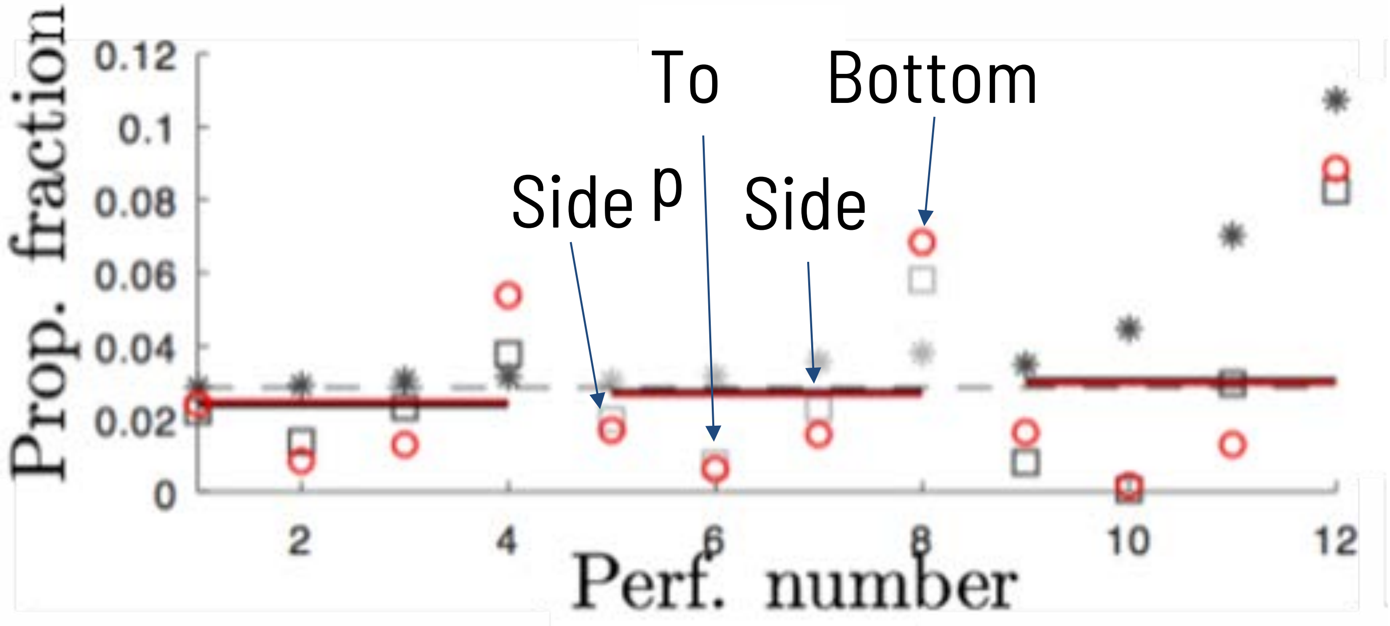
Comparison with lab and yard experiments

Snider et al, SPE-209141-MS, 2022

Lab experiments

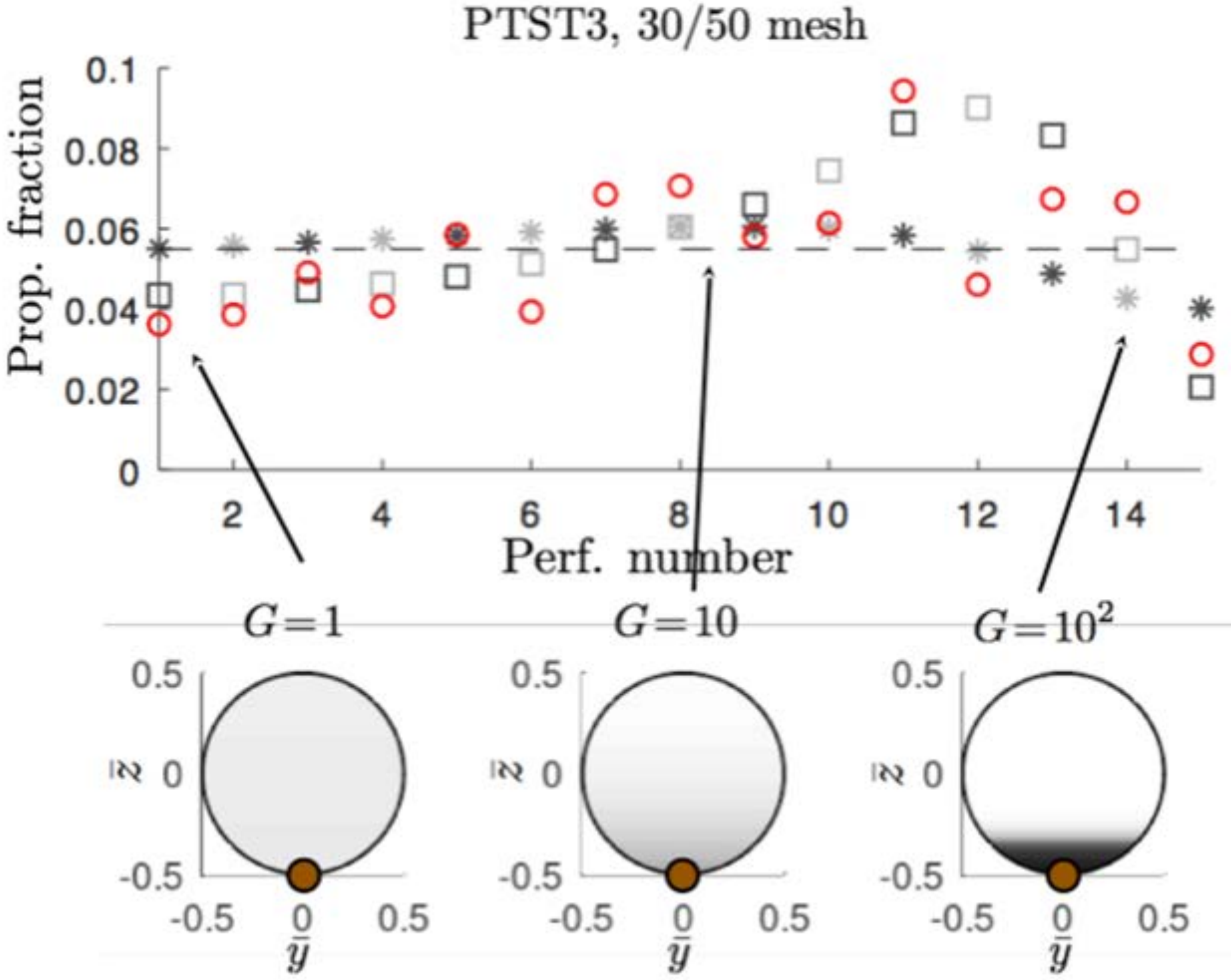


Ahmad et al, urtec-5298, 2021, Liu et al, 2021



3 clusters, 4 shots with 90° phasing

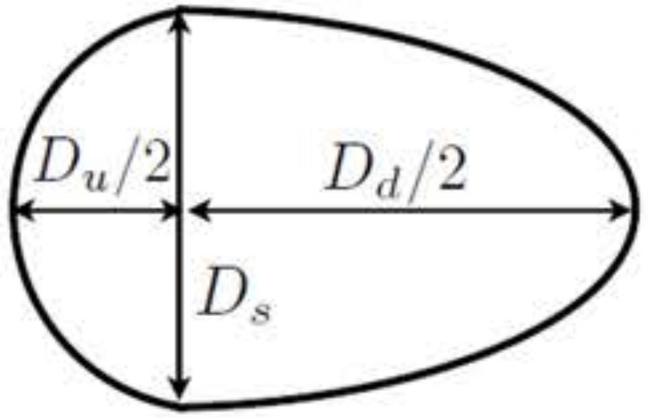
Yard experiments



PTST3 - 15 clusters, 1 perf at the bottom

Perforation erosion

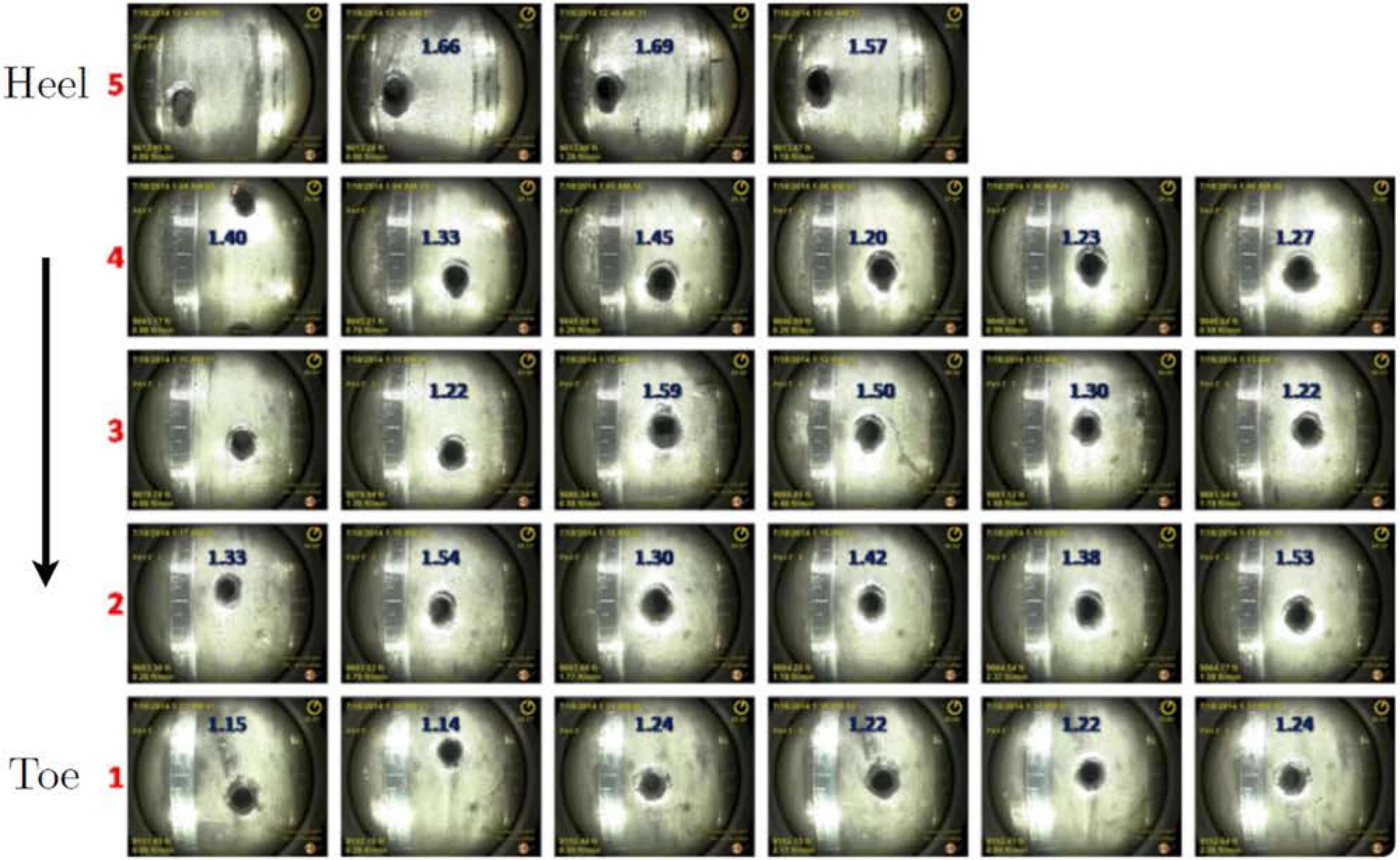
Modified erosion model



$$\frac{dD_u}{dt} = \alpha C v_p^2,$$
$$\frac{dD_s}{dt} = \alpha C v_p^2,$$
$$\frac{dD_d}{dt} = \alpha C (v_p^2 + \gamma v_w^2),$$
$$\frac{dC_d}{dt} = \beta C v_p^2 \left(1 - \frac{C_d}{C_{d,max}}\right).$$

Heel bias

$$D_{eq} = \sqrt{\frac{4A}{\pi}}, \qquad A = \frac{\pi}{8} D_s (D_u + D_d).$$



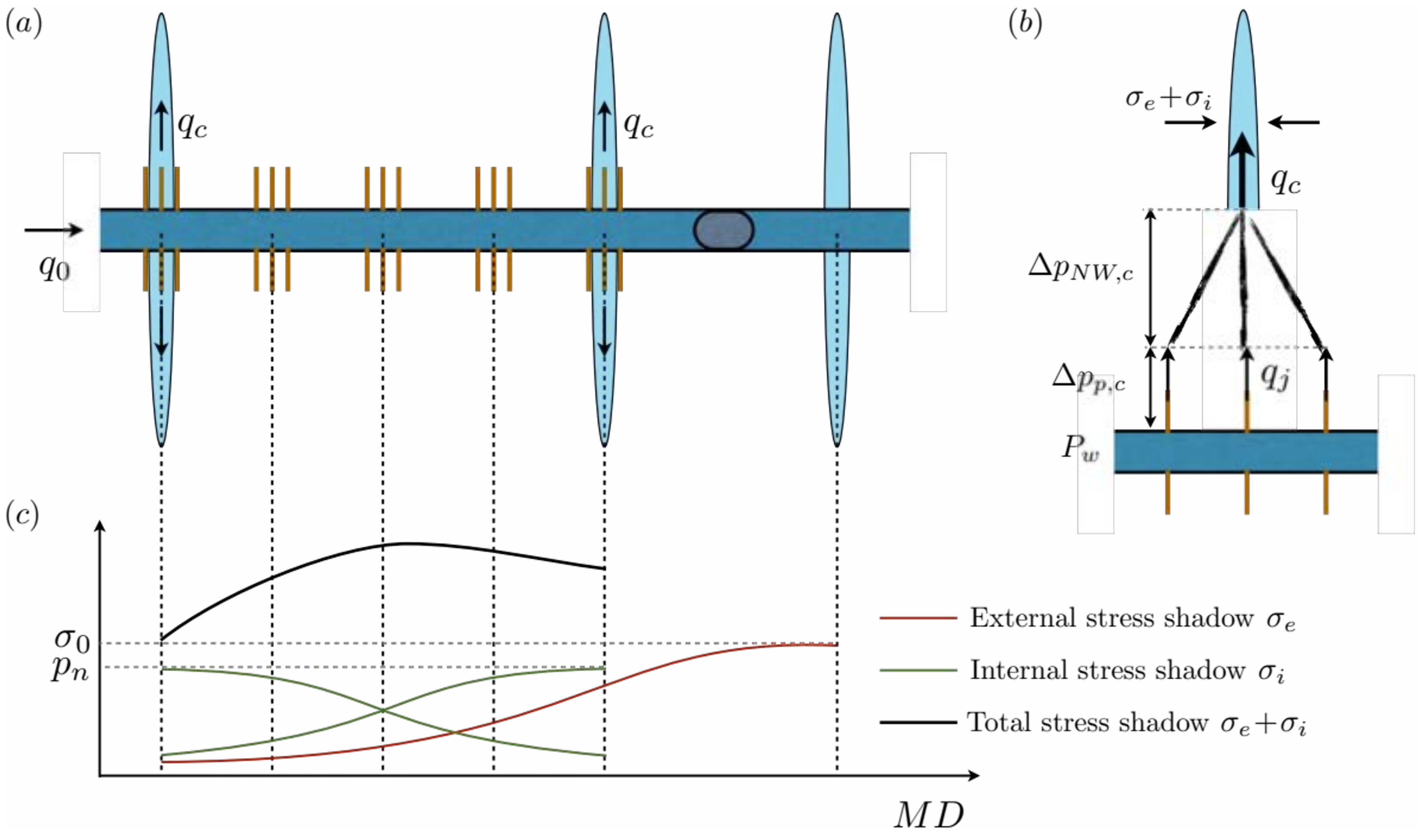
Cramer et al, SPE-194334-MS, 2020

The addition of 'gamma' term allows to capture heel bias and elongated perf shapes

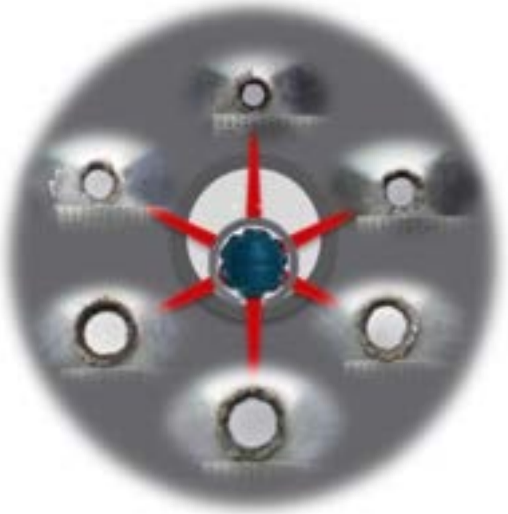
Wellbore dynamics simulator

- The proppant transport and erosion models are incorporated into a fast-running wellbore dynamics simulator.
- Time-steps through the injection schedule, calculating distribution of flow and erosion in every timestep.
- We consider:
  - Breakdown of perfs
  - Perforation pressure drop
  - Near-wellbore pressure drop
  - Stress shadowing (prior stage and within the stage)
  - Random variance in phasing, diameter, breakdown pressure, and erosion (Monte Carlo)

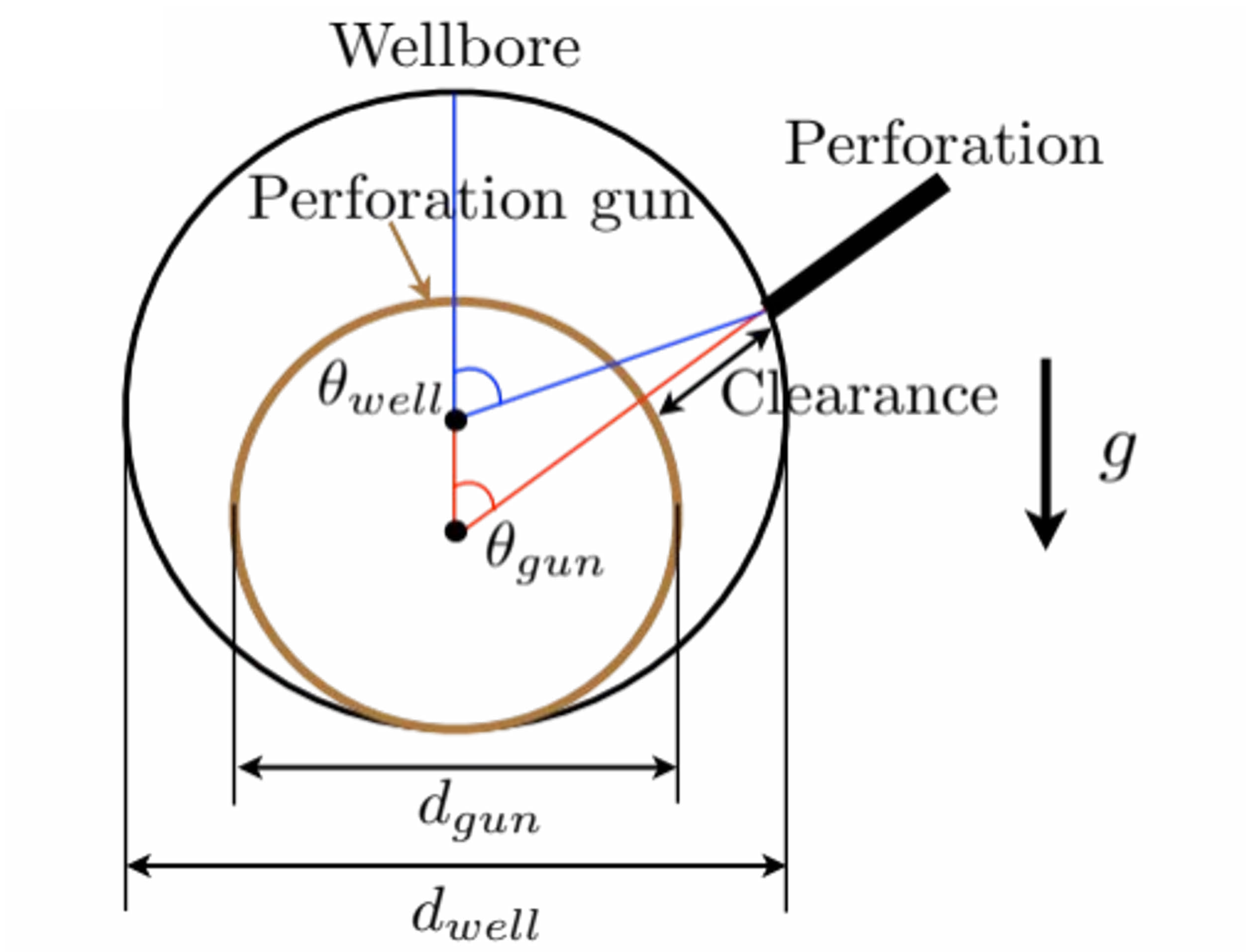
Sketch for the model

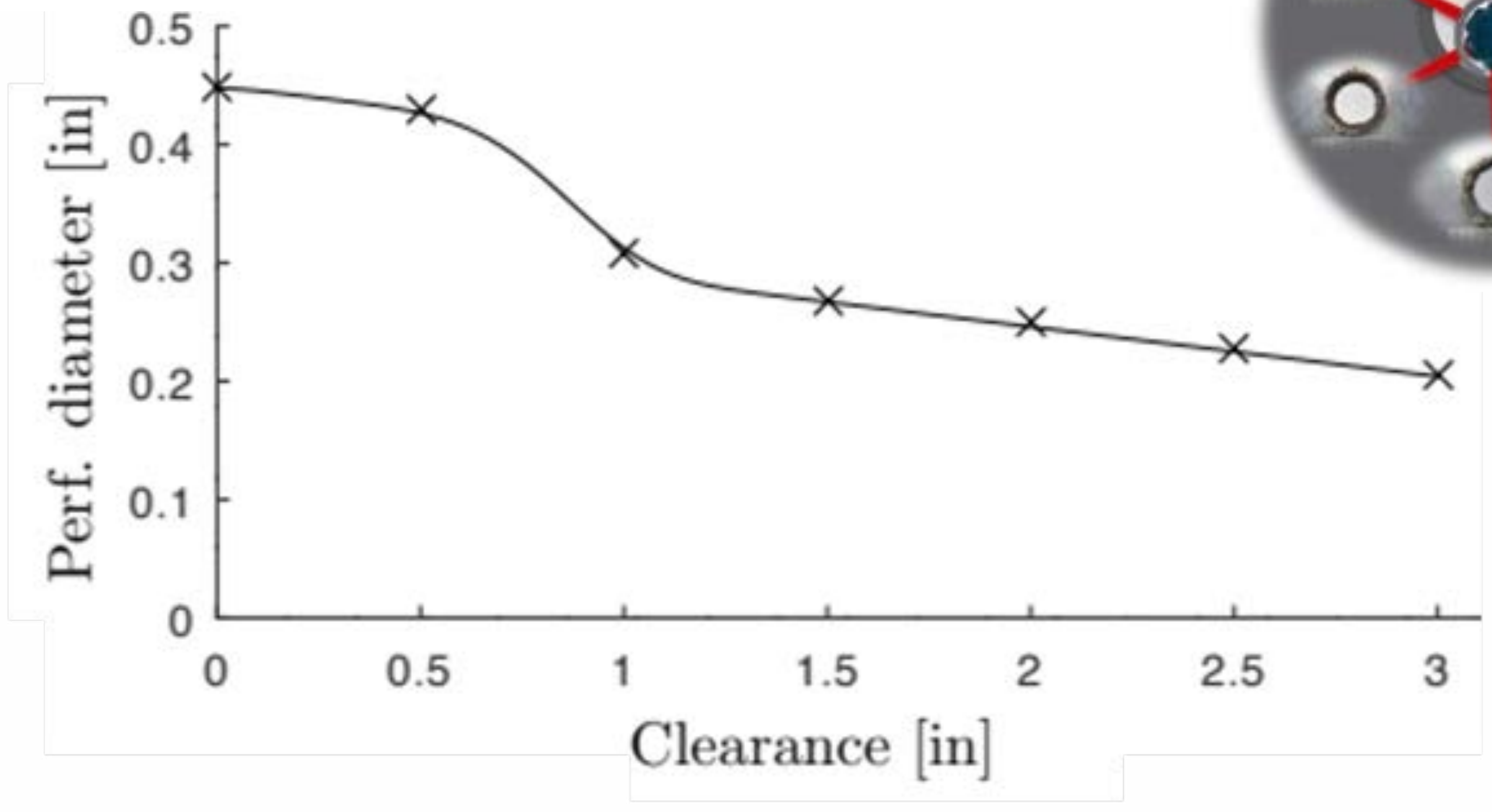


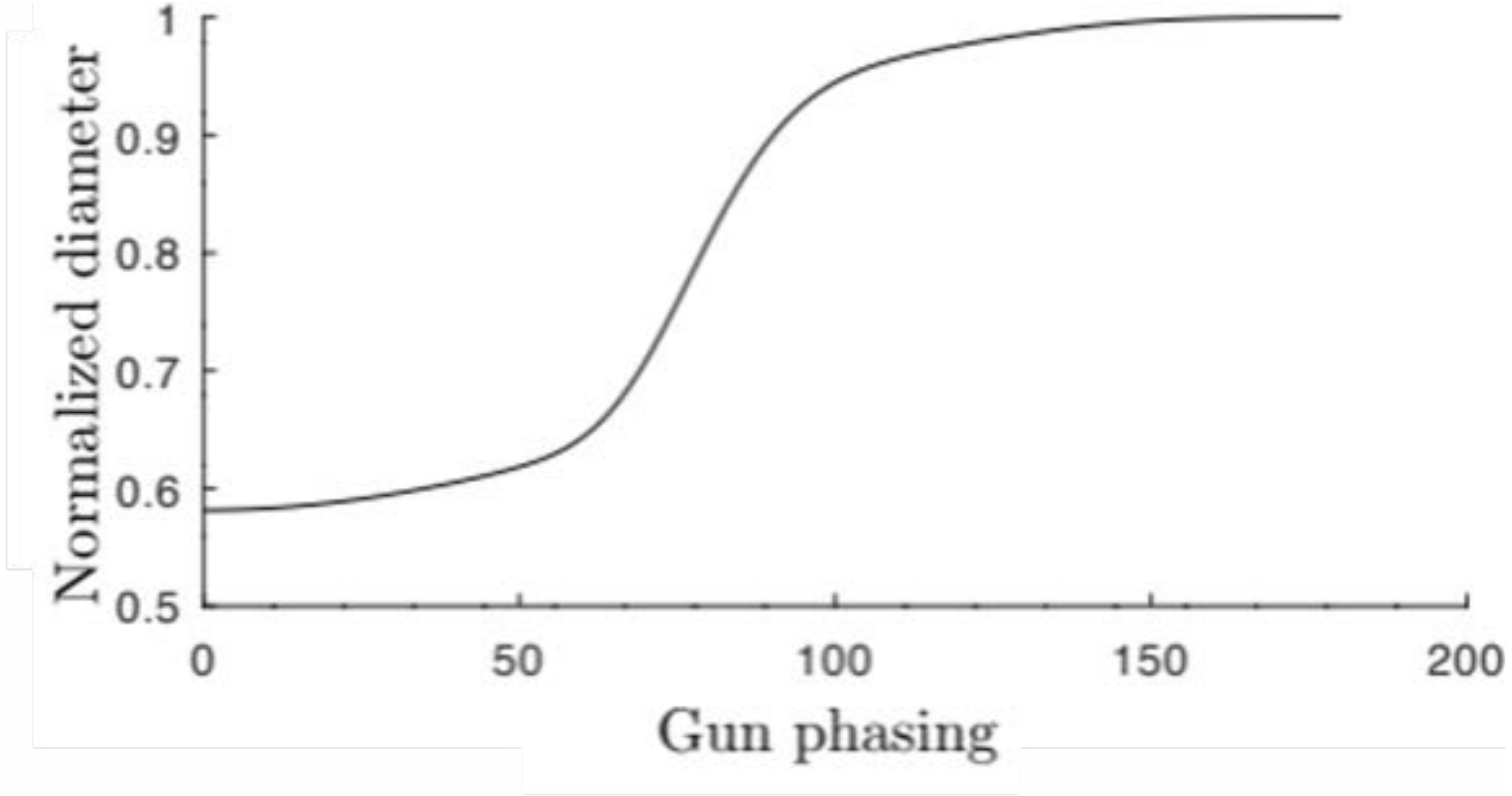
Perforation gun related features



- The difference between the gun centered phasing and well centered phasing
- Variation of perforation diameter vs gun clearance

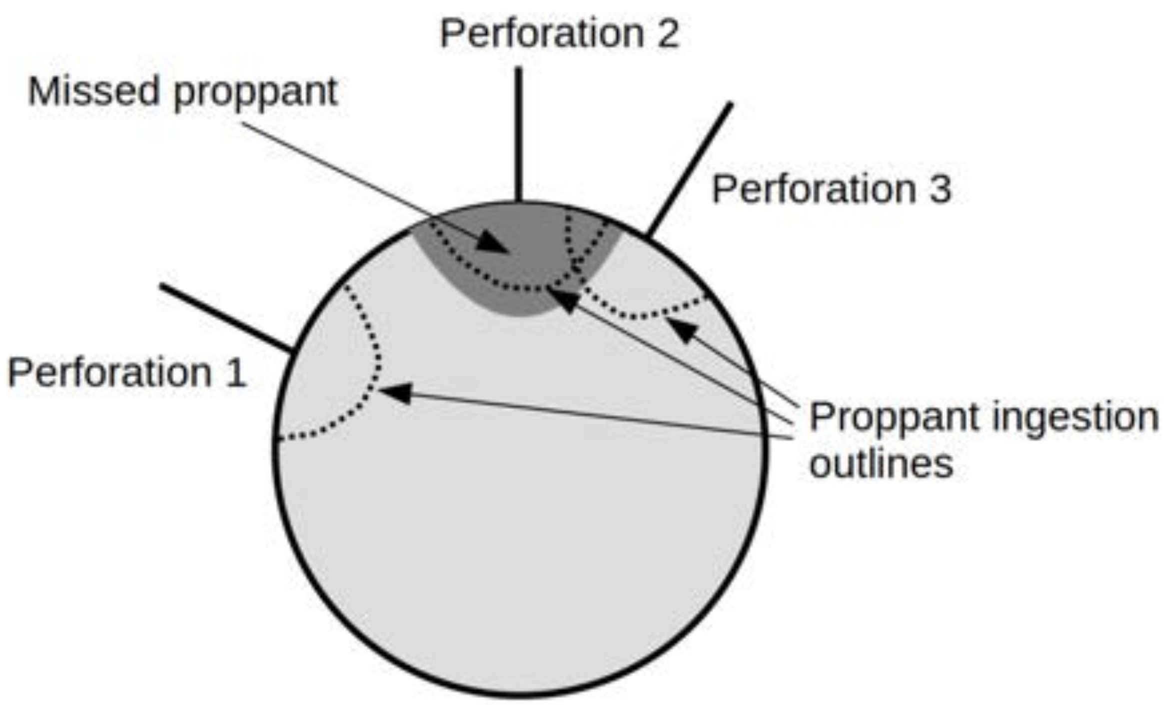




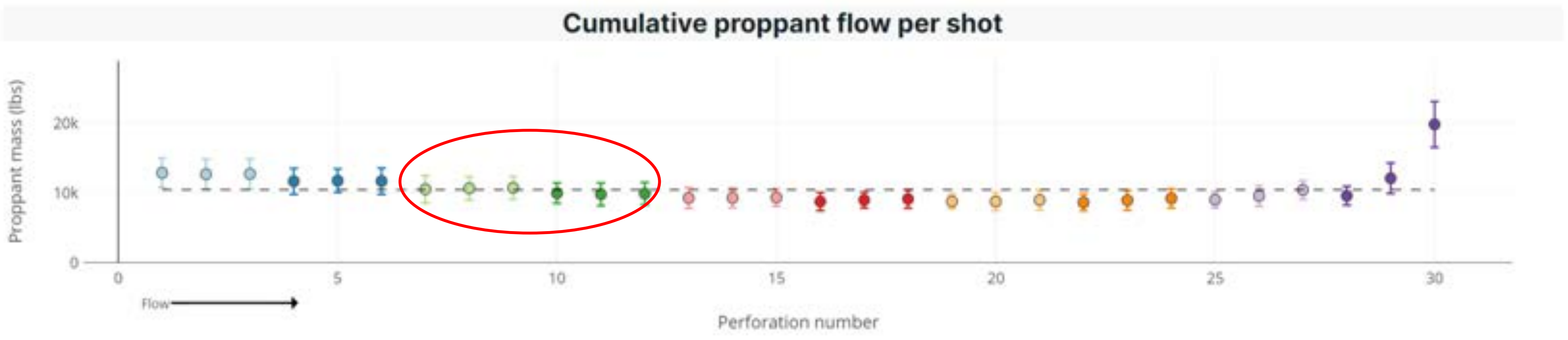


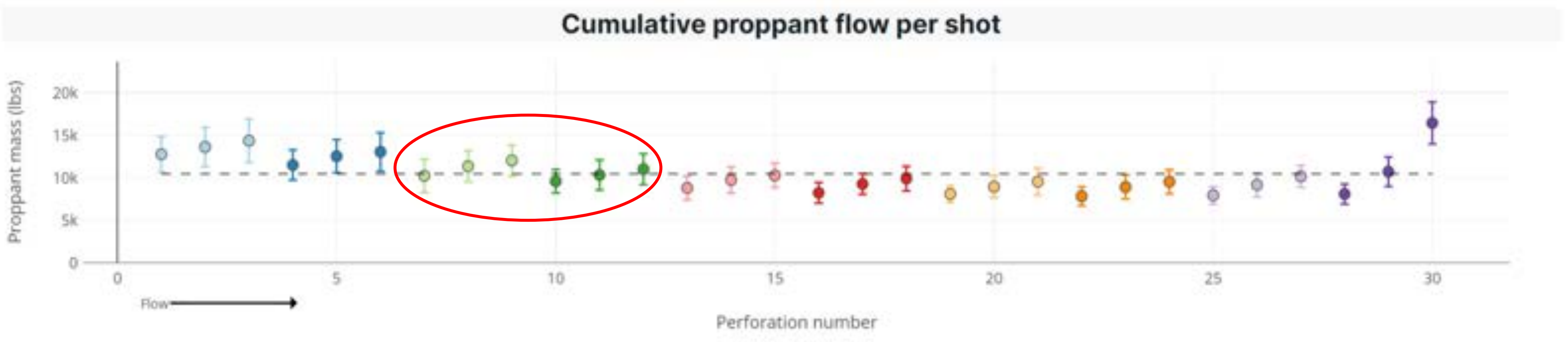
Correction for inline perfs

- Oriented perforations are often used in the field.
- Proppant that 'misses' the first perforation turns into the next perforation if both are located inline.
- The third perforation gets even more proppant.
- Thus, there is a tendency for a gradually increasing erosion for the inline perforations.



Generic simulation with 10 clusters, 3 shots at 0°

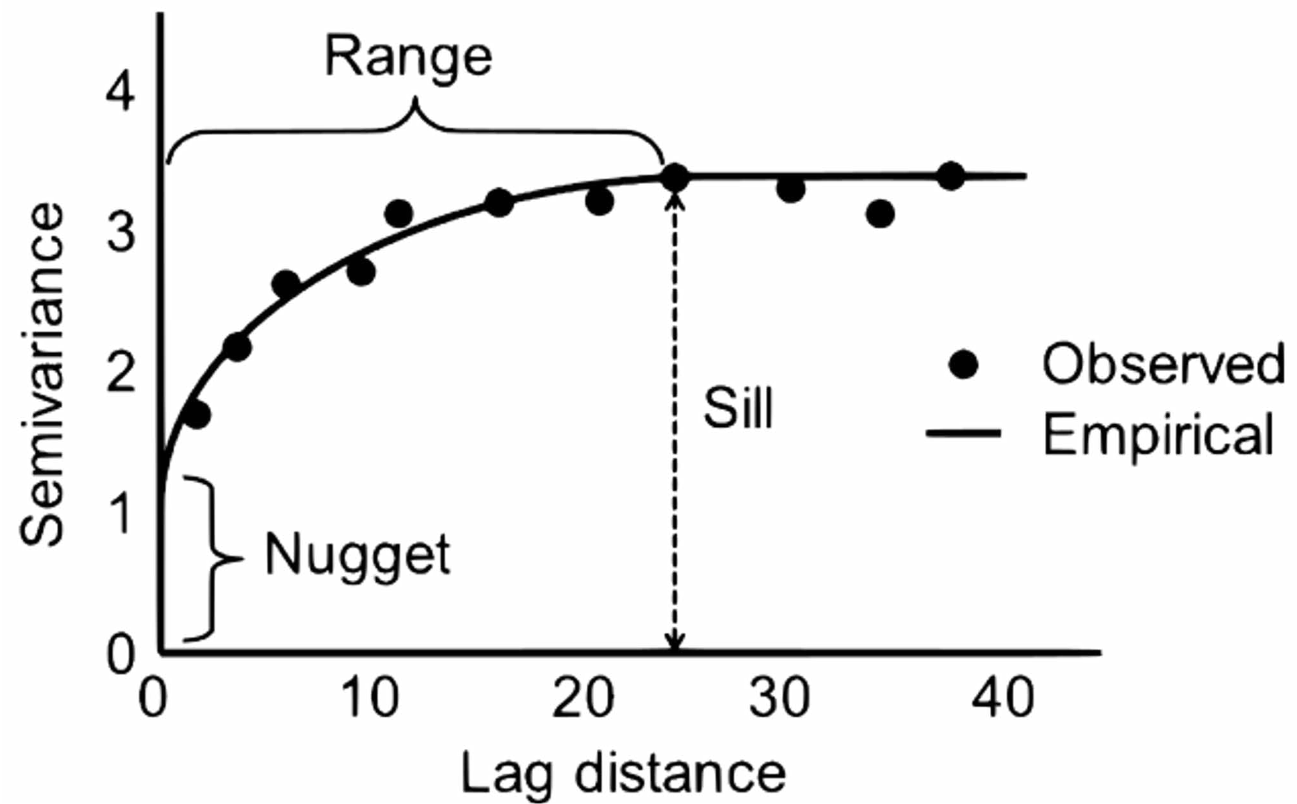




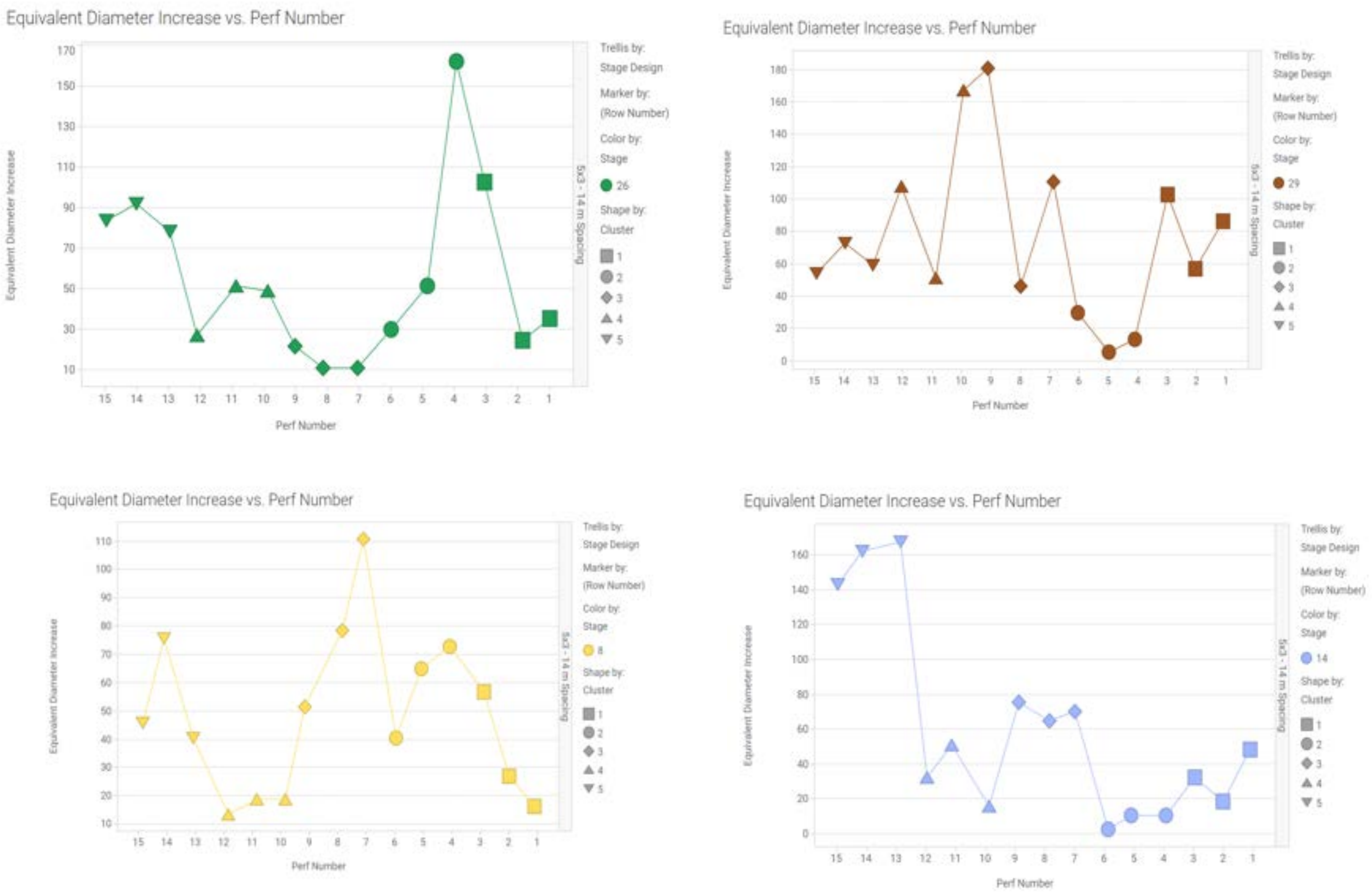
Inline effect

Spatial variability of erosion

- Erosion data averaged over multiple stages typically has a gradual trend.
- But the result for each individual stage is often very variable and lacks a particular trend, but has some spatial correlation.
- To capture such variability, we introduce spatially correlated randomness of erosion rate.

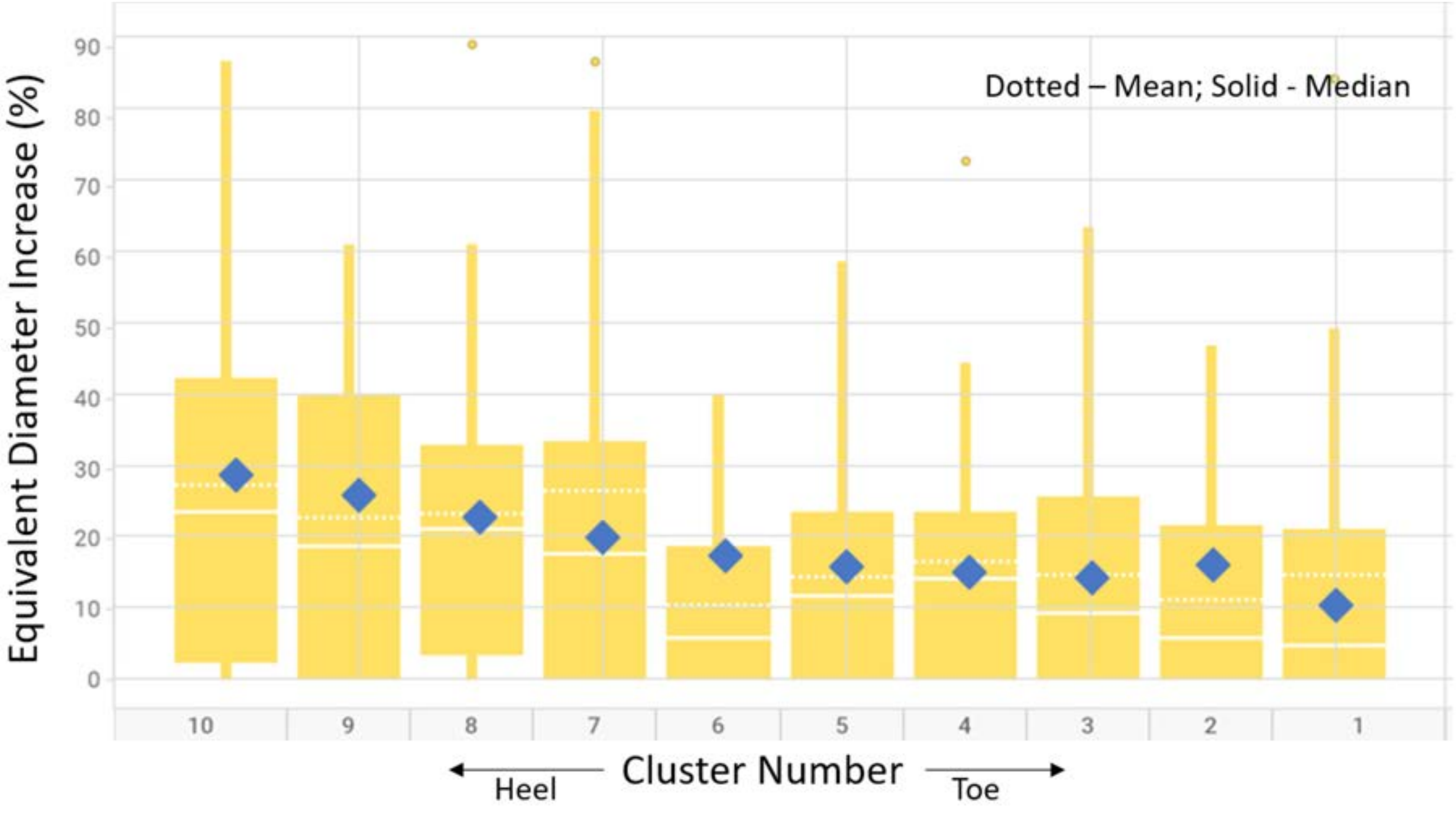


Data for 4 individual stages

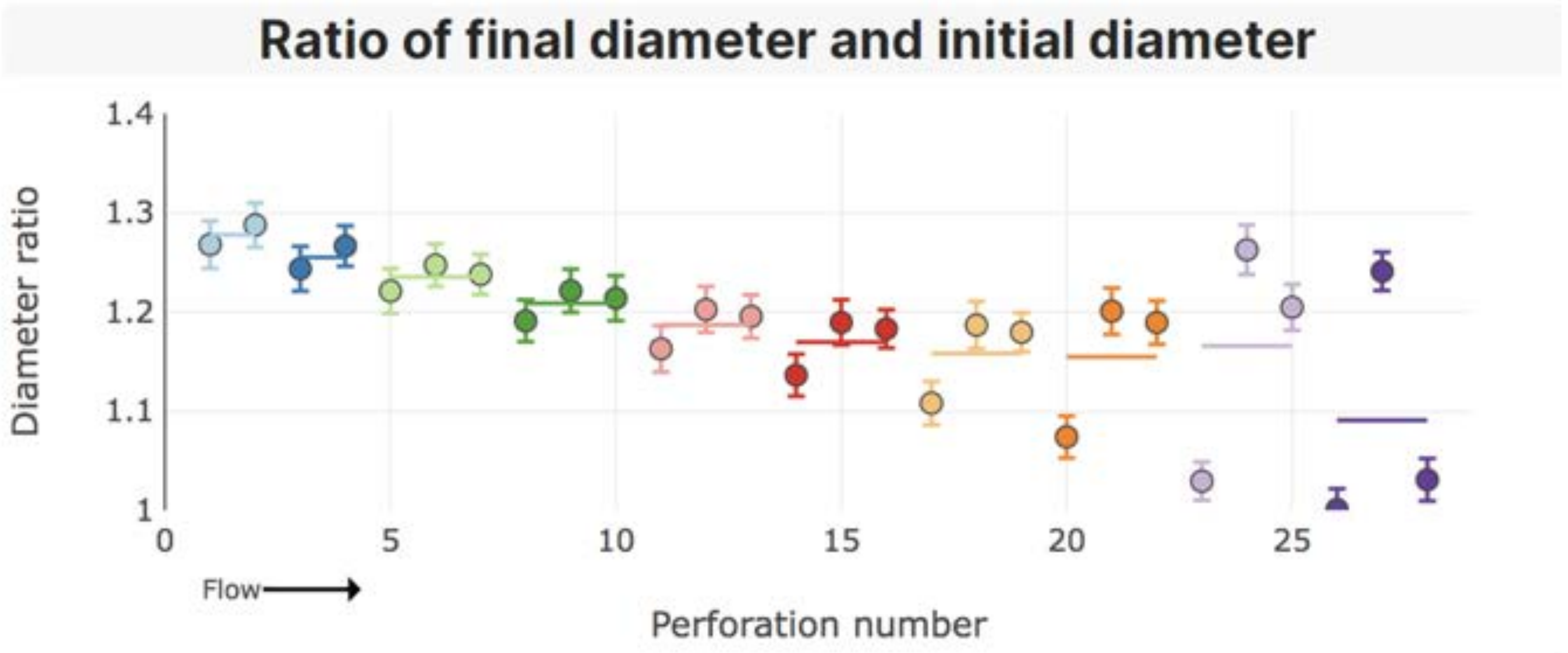


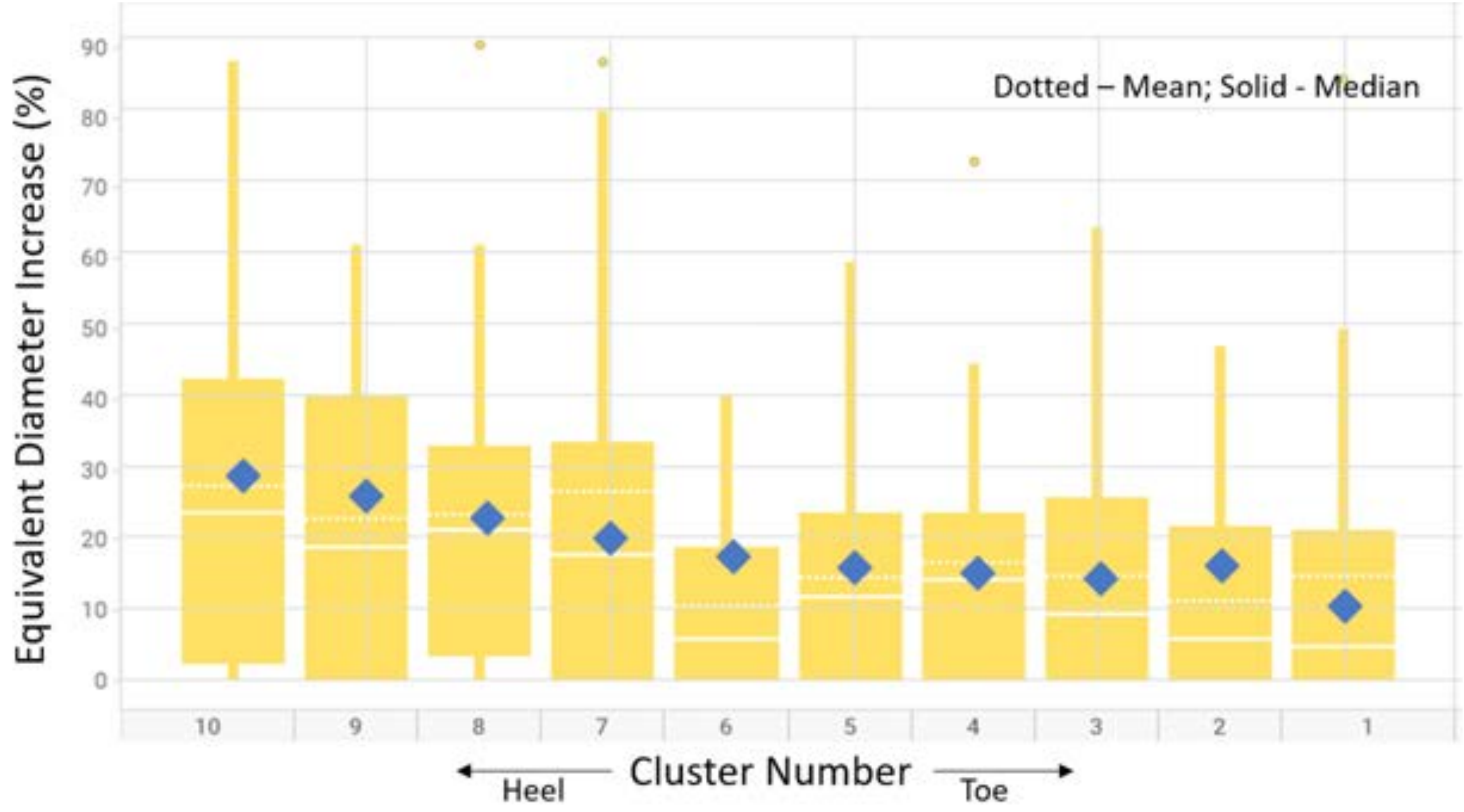
Case study 1

- Eagle Ford.
- Unoriented 120' phasing perforations – 3 shots per cluster (except two heel clusters had 2 shots).
- 180 ft stage length, 10 clusters per stage.
- Heel erosion bias is observed.

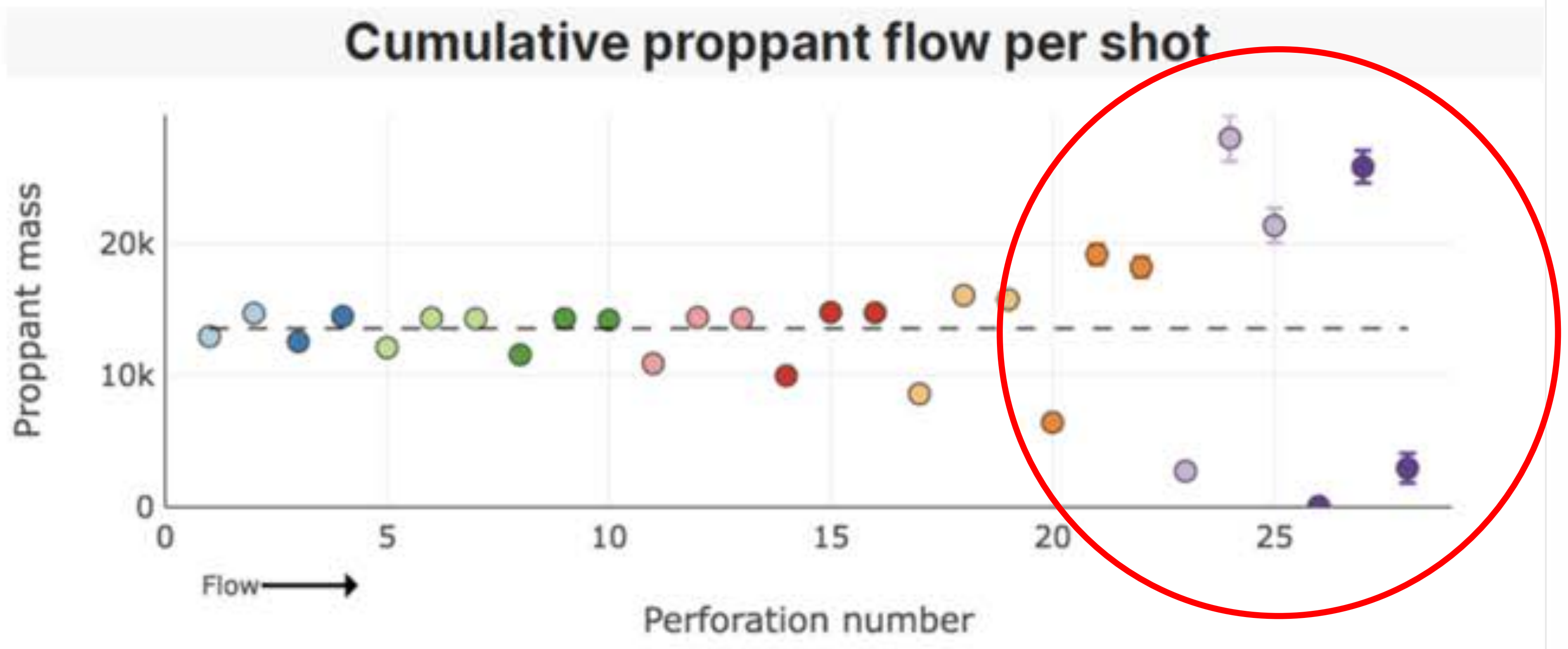


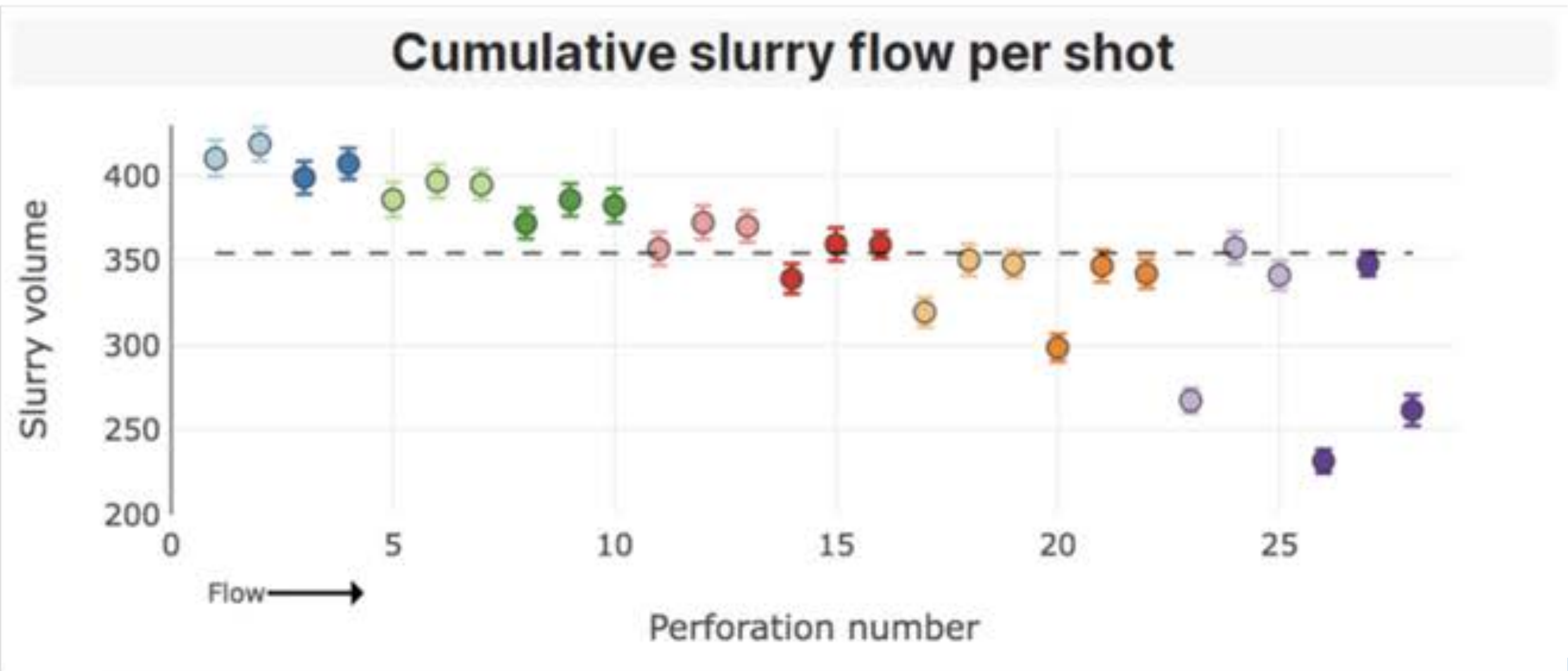
Case study 1: field vs model



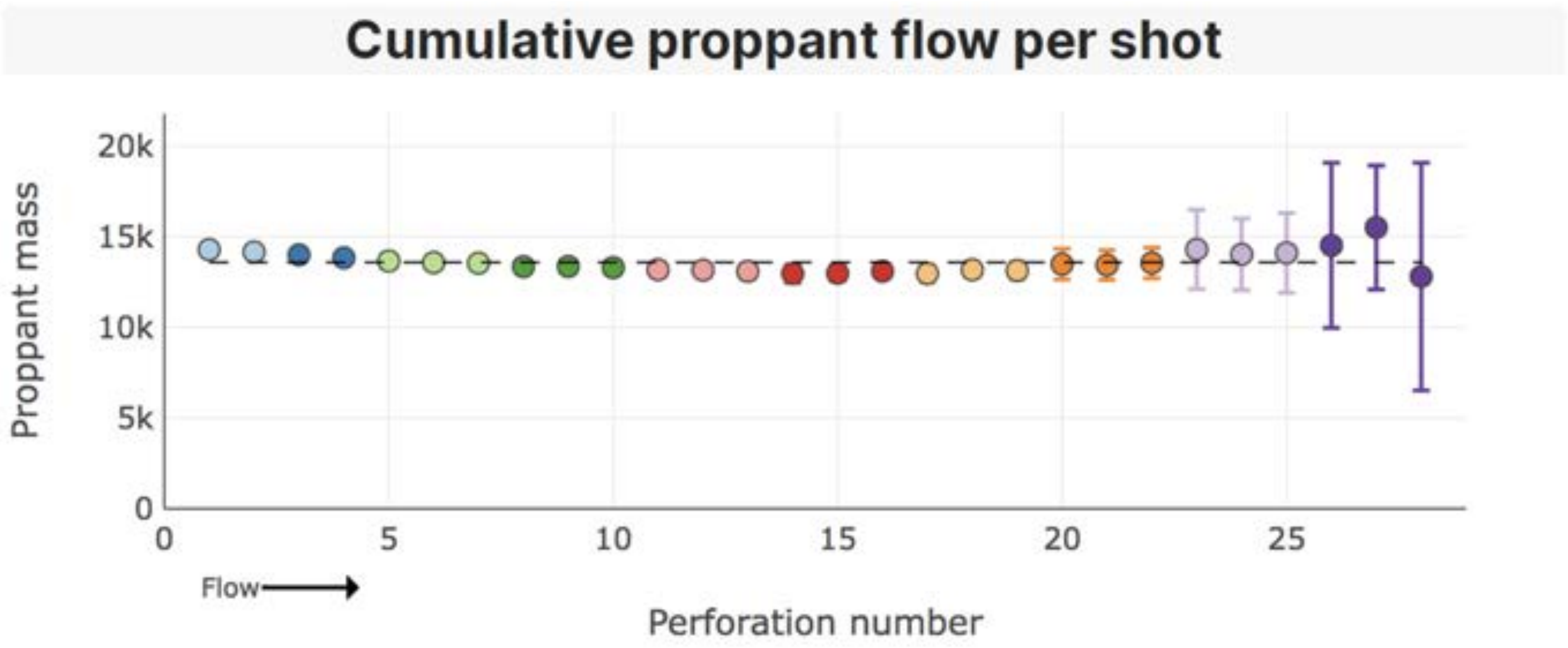


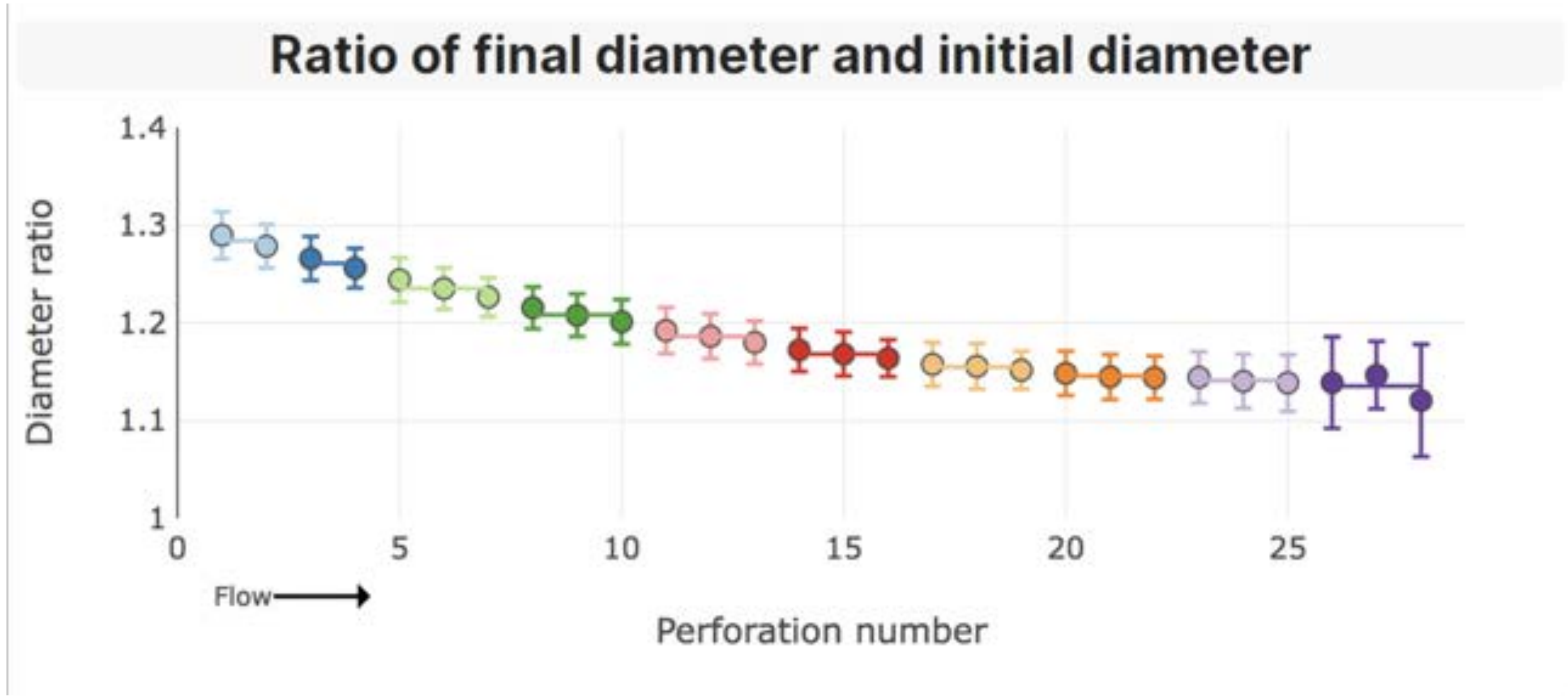
Strong flow segregation



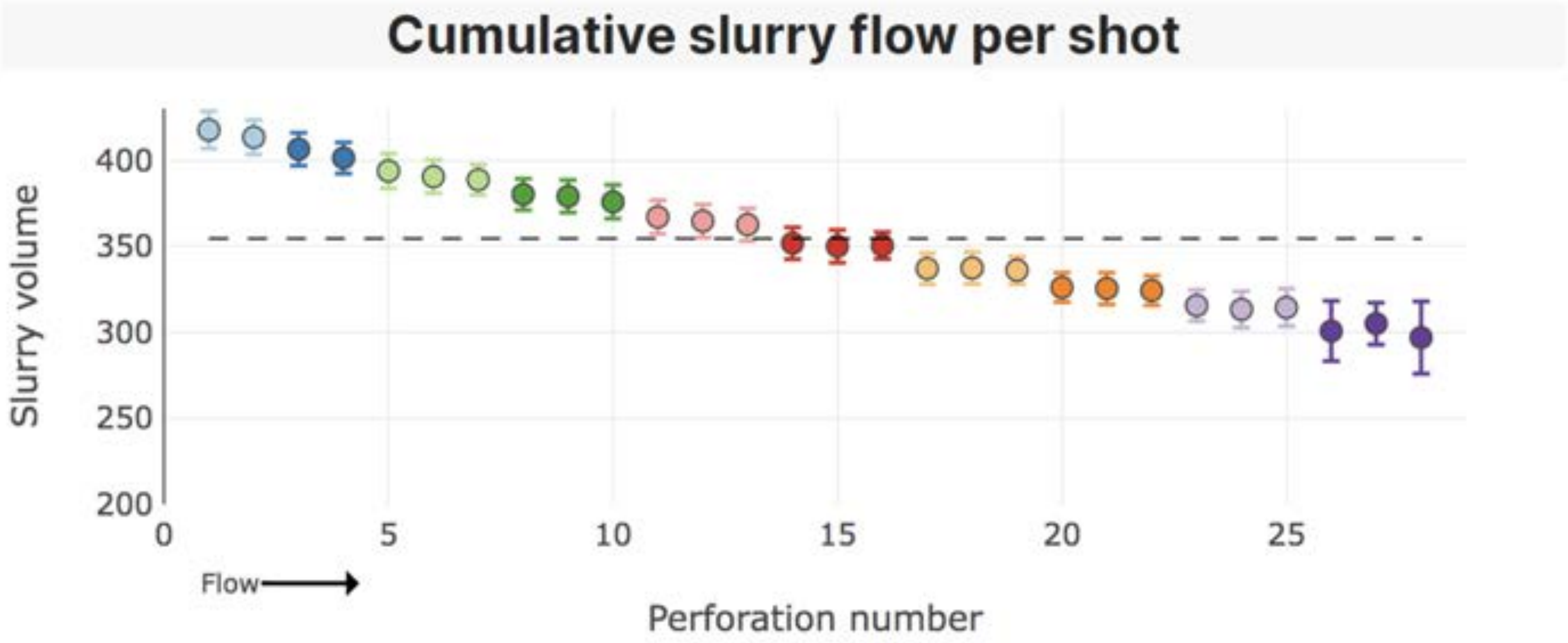


Case study 1: optimal phasing



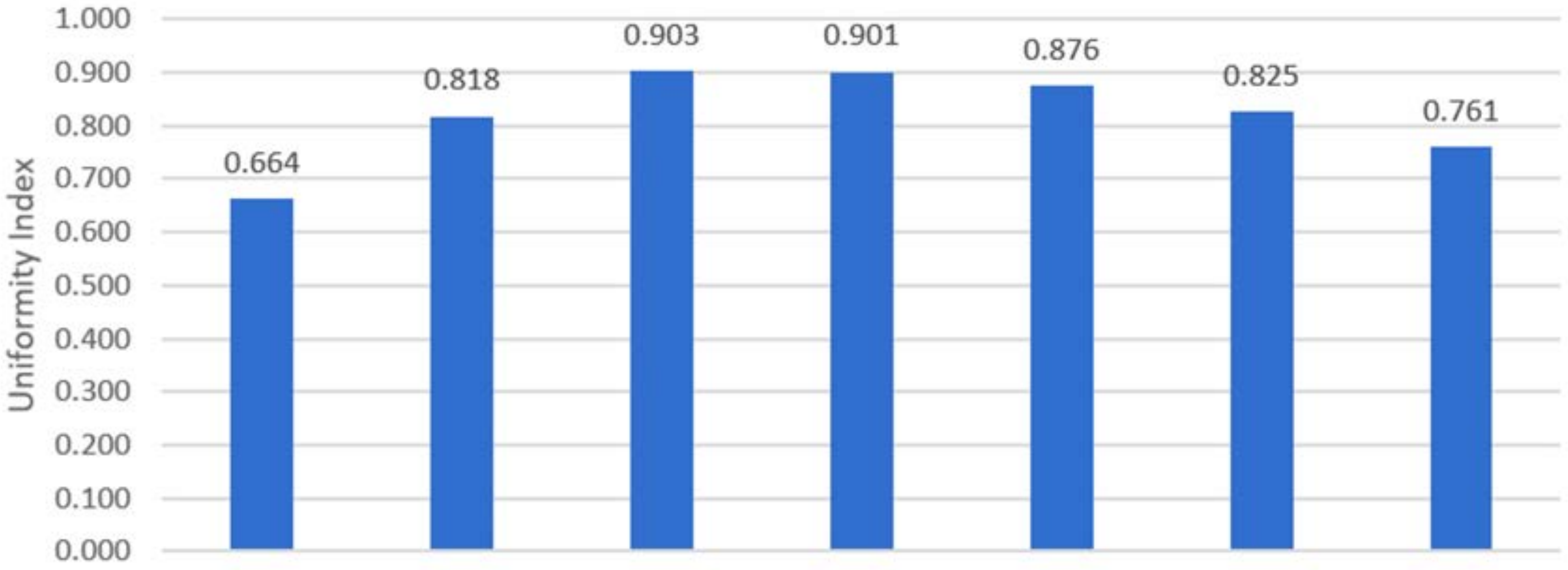


- Oriented optimal phasing.
- Goal: uniform proppant distribution.
- Proppant is nearly uniform.
- Erosion still has heel bias.
- Slurry aso has heel bias.
- No sharp variation from perf to perf.



Case study 1: optimal limited entry

- The plot shows uniformity index as a function of perforation pressure drop.
- Proppant uniformity index is low if the perforation friction is low.
- Interestingly, if there is too much limited entry, this harms uniformity too. Erosion becomes very strong, and it strongly contributes to nonuniformly.
- There is an optimal limited entry level that maximizes uniformity.



Perforation friction

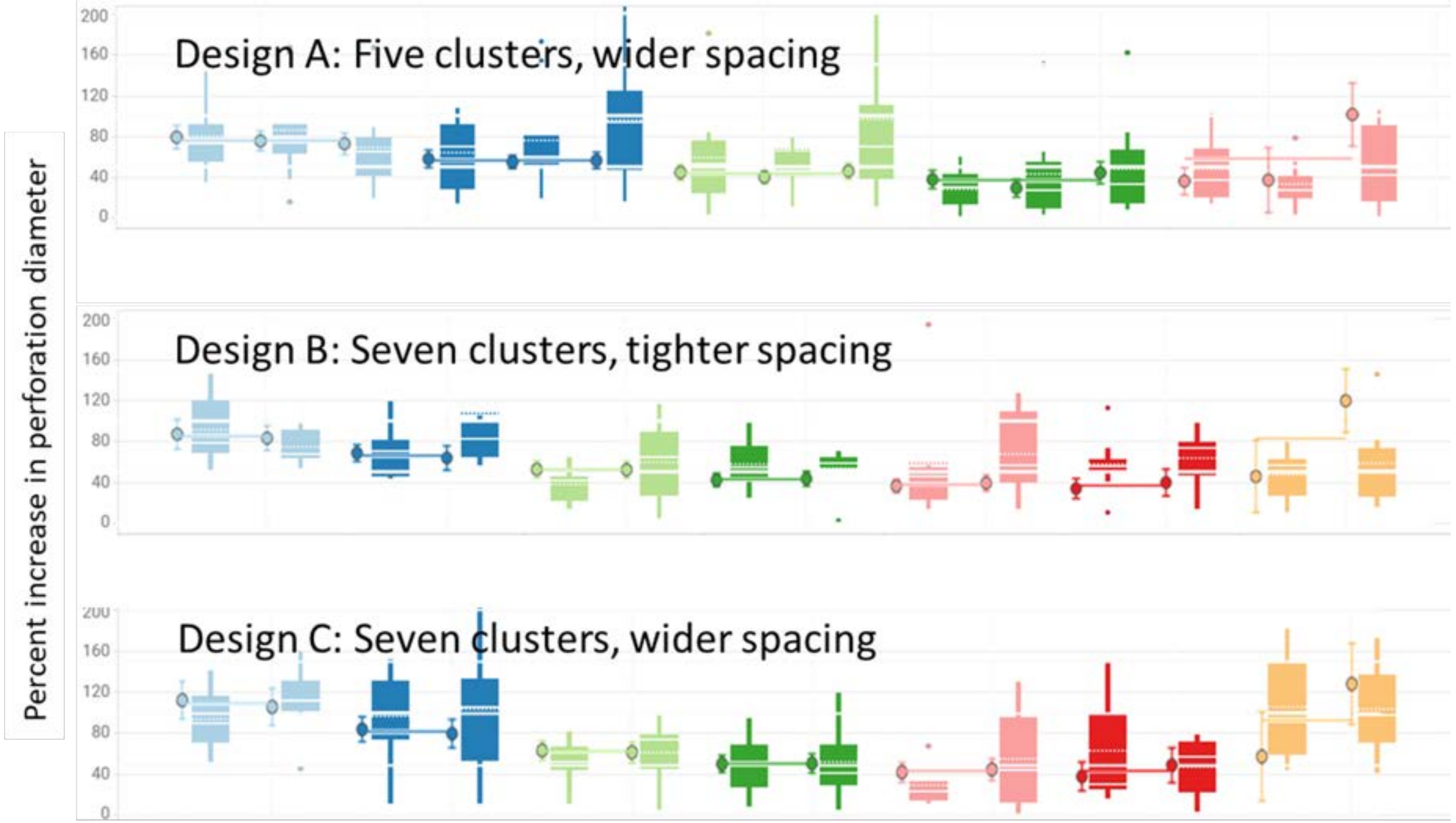
Why

- Improvements in uniformity translate directly into production.
- Increasing UI from 0.5 to 0.75 is worth approximately $500k per well.
- Increasing UI from 0.75 to 0.9 is worth an additional $500k per well (Cipolla et al. 2024).

Case study 2

- Montney.
- Shots oriented in the upper 120° of the well, about the same number of perfs.
- Designs A and B have same stage length, but 5 or 7 clusters.
- Designs B and C have same cluster count, but C has a longer stage length.
- Constant fluid/proppant volume per ft.
- The proppant distribution is U shaped, with both a toe and heel bias.
- The overall erosion in this dataset was greater than in the prior one, and so the overall erosion coefficient was set to a higher number.

Field vs model

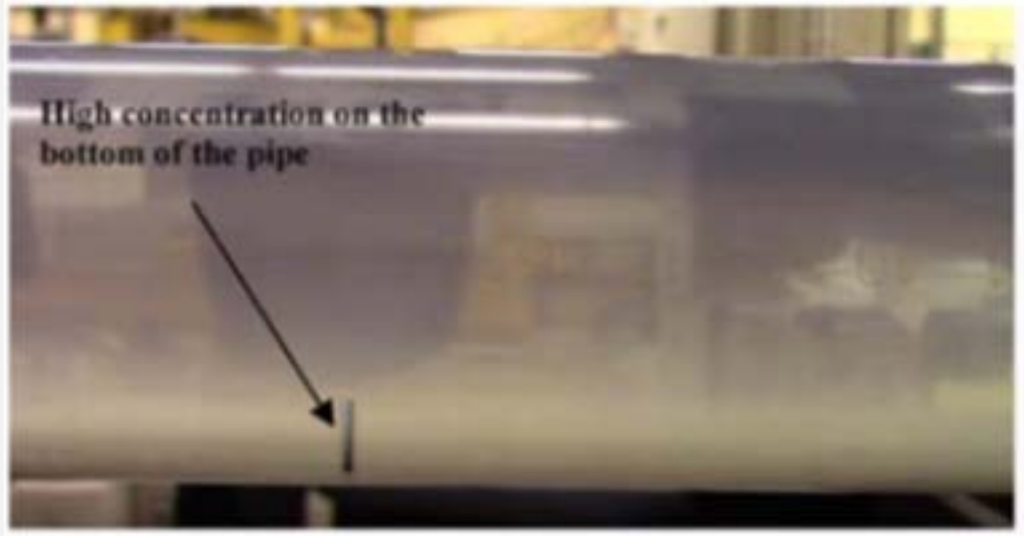


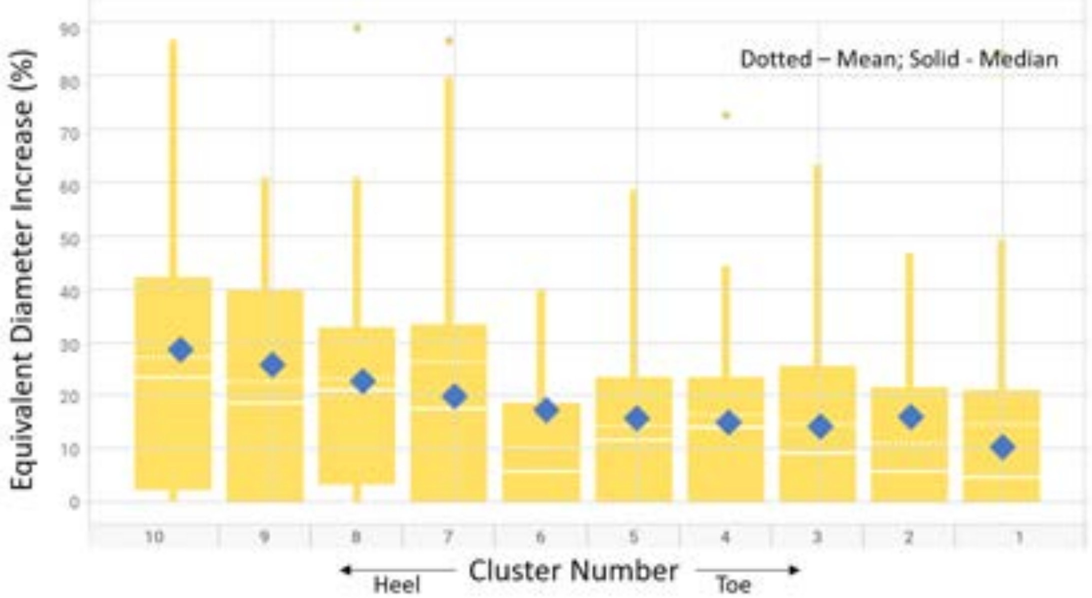
Summary

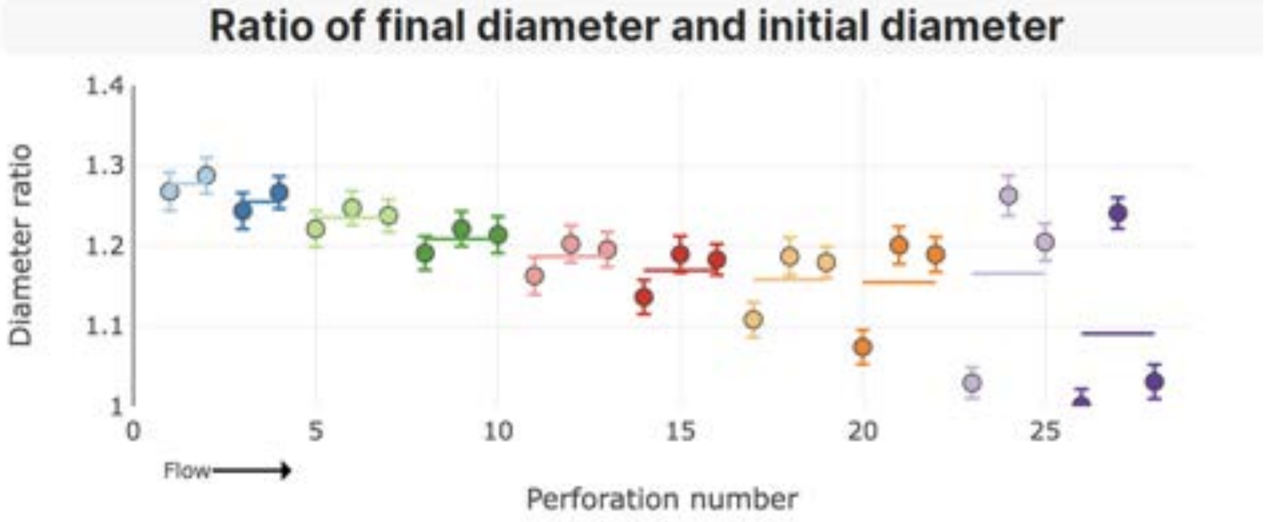
- Primary physical mechanisms affecting proppant distribution in a perforated wellbore: particle settling, particle turning, perforation erosion.
- A fast running model is developed and is calibrated against available laboratory scale, yard scale, and computational data.
- Two history matched field cases are presented.
- Optimization of phasing and limited entry increase uniformity index.

- We gratefully acknowledge the contributions of two operators who provided the data for the case studies for this paper.
  - Case Study 1 was provided by an anonymous operator.
  - Case Study 2 was provided by Arc Resources. We appreciate the collaboration with colleagues with Arc Resources, including Justin Kitchen, Mani Mehrok, Pierce Anderson, and Farhan Alimahomed.

Publications: Dontsov 2023 IJMF, arXiv:2301.10855, ARMA 23-348, URTeC 3854538, SPE 217771-MS







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QUESTIONS?

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