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Perturbation Decay Experiments on Granular Materials

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Sakharov et al. Perturbation Decay Experiment

Sakharov, A. D., R. M. Zaidel, V. N. Mineev and A. G. Oleinik (1965). "Experimental investigation of the stability of shock waves and the mechanical properties of substances at high pressures and temperatures." *Soviet Physics JETP* **9**: 1091-1094.

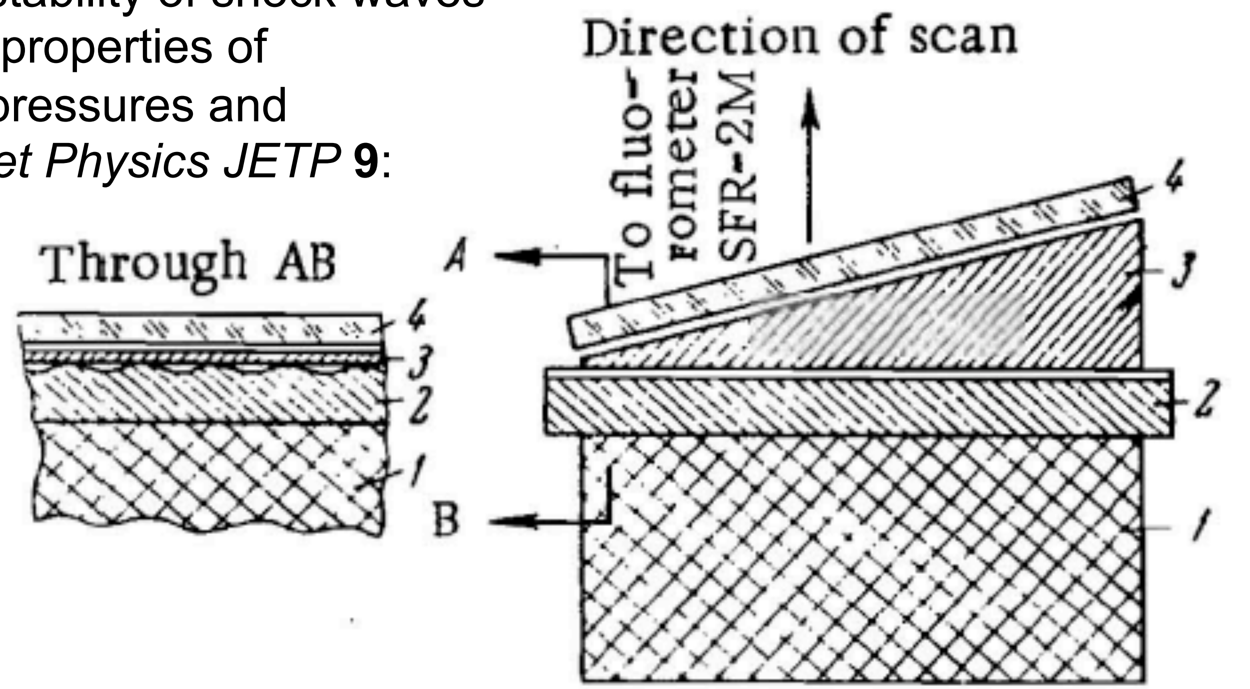
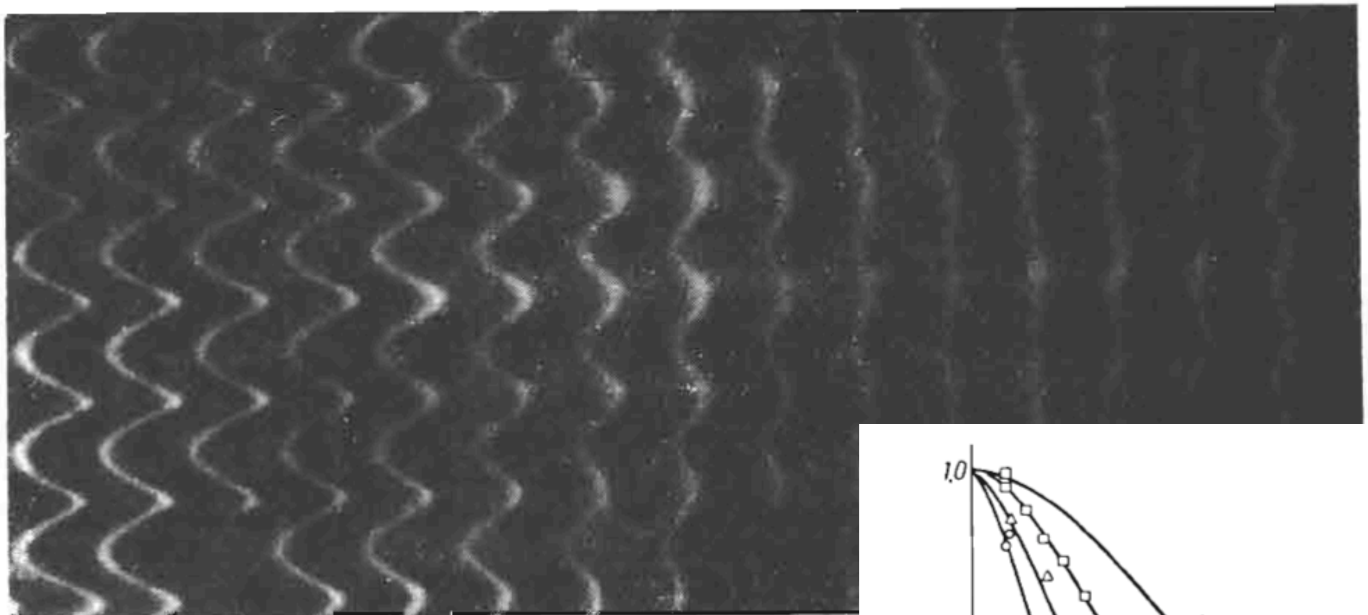


Fig. 1. Diagram of experimental arrangement: 1) Explosive charge; 2) grooved disc; 3) wedge; 4) plastic plate.

Measured Perturbation Decay



why no work of this type in the west?

- *tested solids (e.g. Al) and liquids (e.g. H_2O)*
- *viscous fluid analysis*
- *boundary conditions problematic*

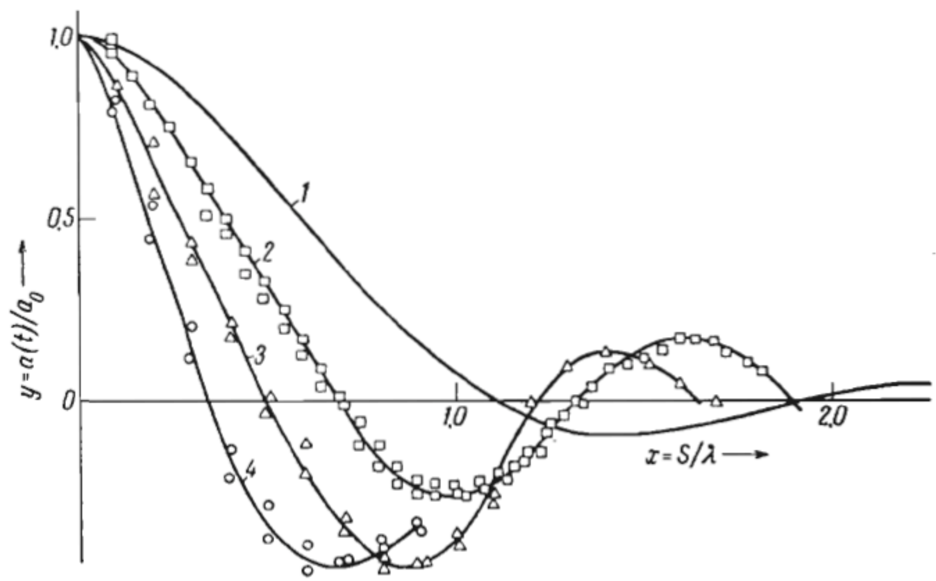


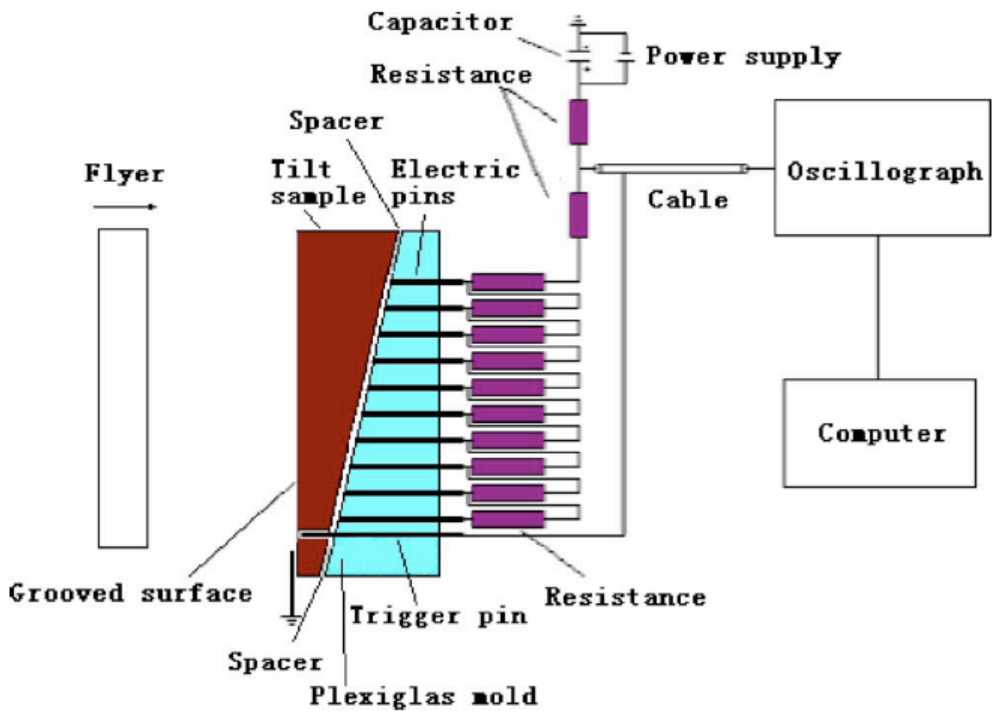
Fig. 3. Some experimental curves of the development of perturbations at a shock-wave front. 1) Calculated curve; 2) λ = 2 cm; ka_0 = 0.872; 3) λ = 1 cm, ka_0 = 0.872; 4) λ = 1 cm, ka_0 = 1.74.

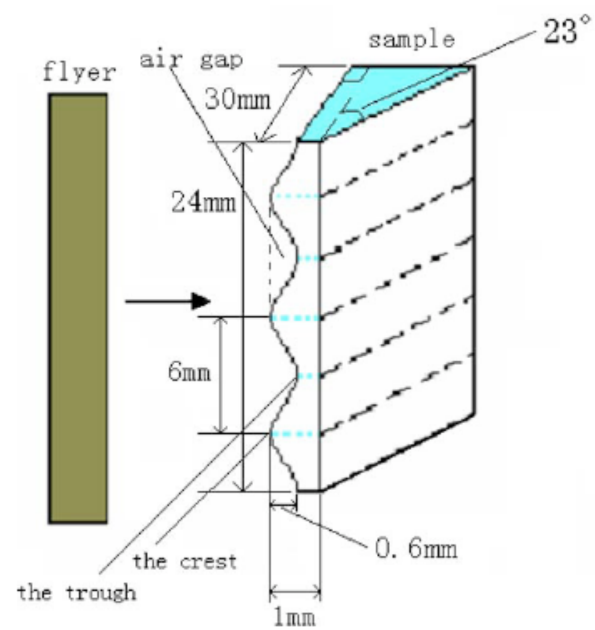
Recent Chinese Studies

Ma, X., F. Liu, M. Zhang and Y. Sun (2011). "Viscosity of aluminum under shock-loading conditions." *Chinese Physics B* **20**: 068301.

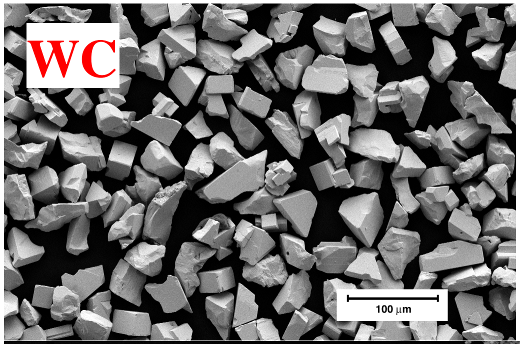
Li, Y., F. Liu, X. Ma, Y. Li, M. Yu, J. Zhang and F. Jing (2009). "A flyer-impact technique for measuring viscosity of metal under shock compression." *Review of Scientific Instruments* **80**: 013903.

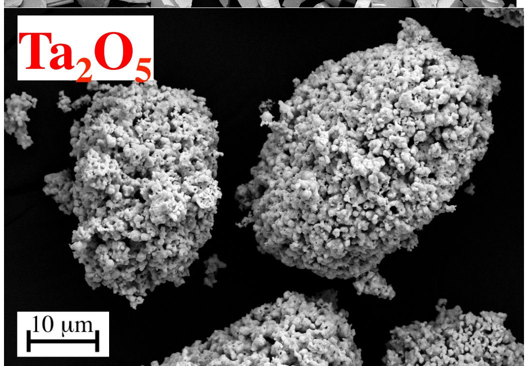
Ma, X., F. Liu, Y. Sun, M. Zhang, X. Peng and Y. Li (2011). "Effective shear viscosity of iron under shock-loading condition." *Chinese Physics Letters* **28**: 044704.



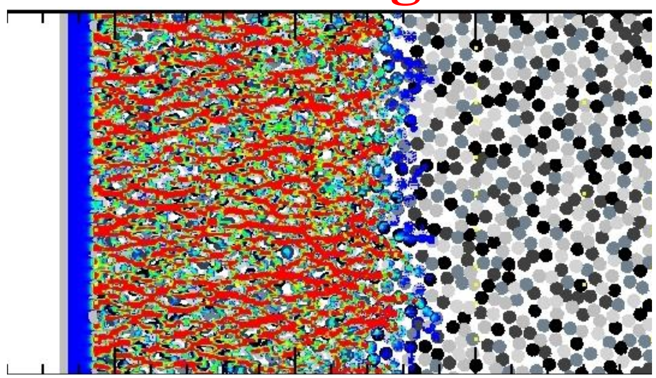


Granular Materials Investigations

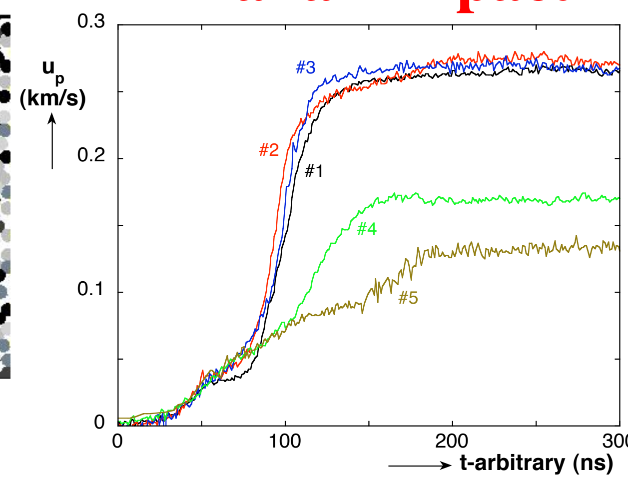


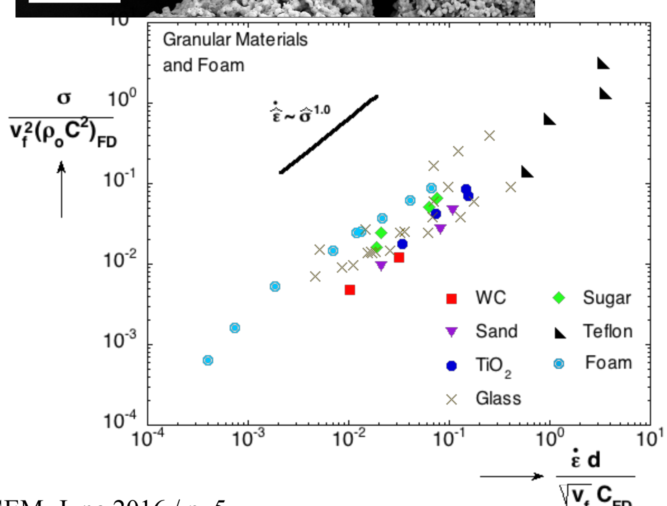


Mesoscale Modeling

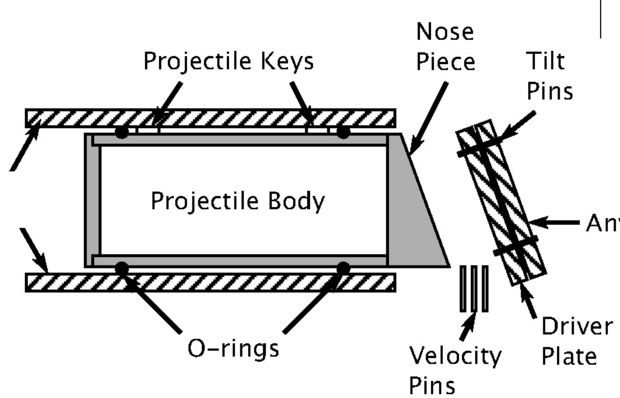


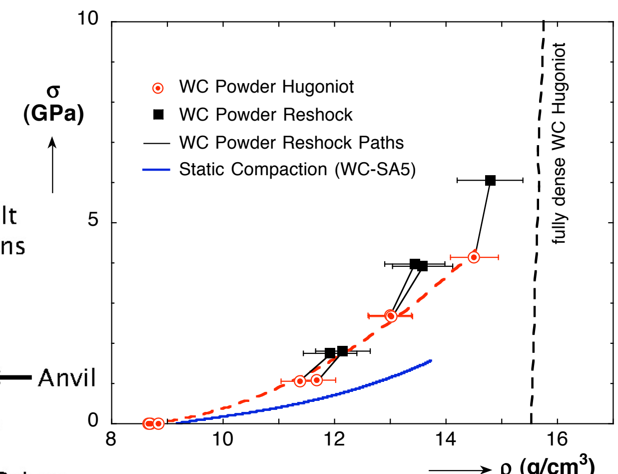
Planar Impact





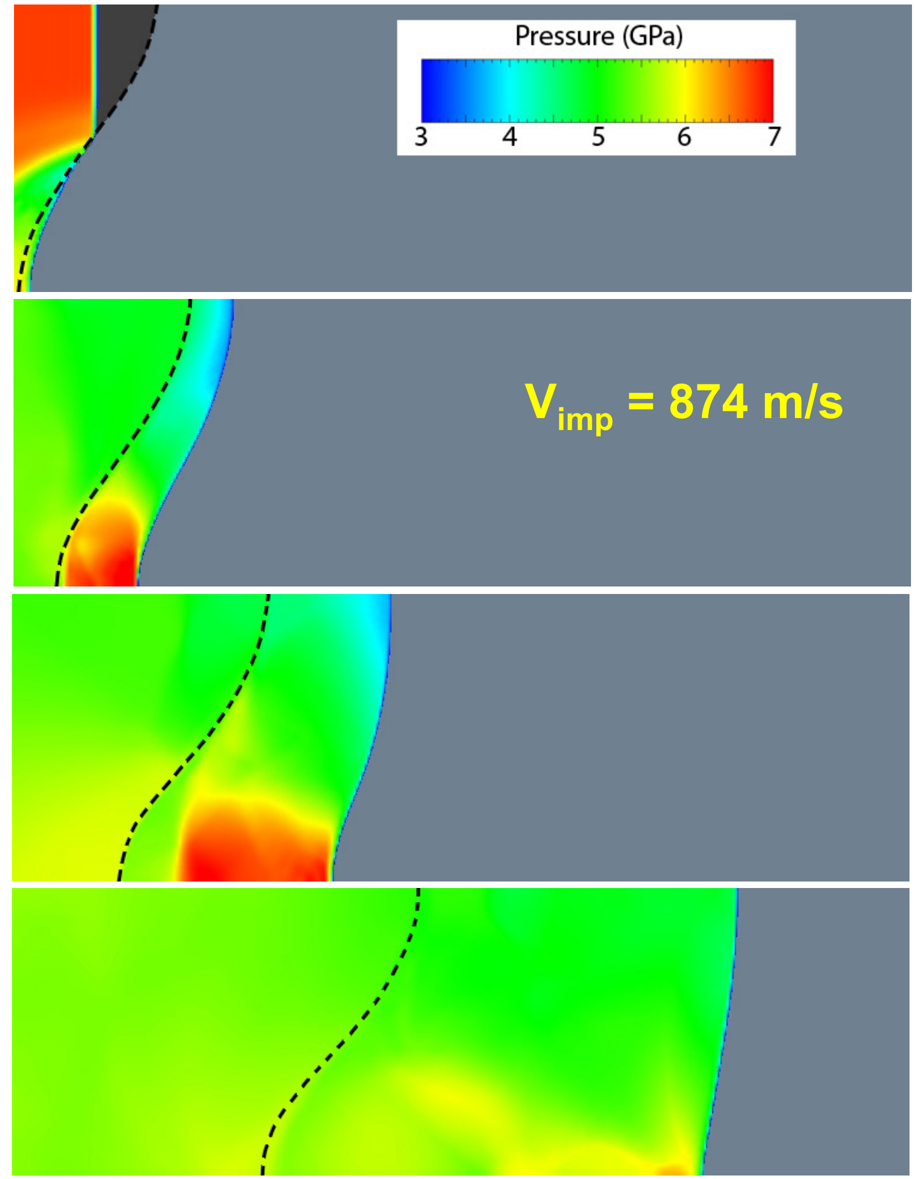
Pressure-Shear



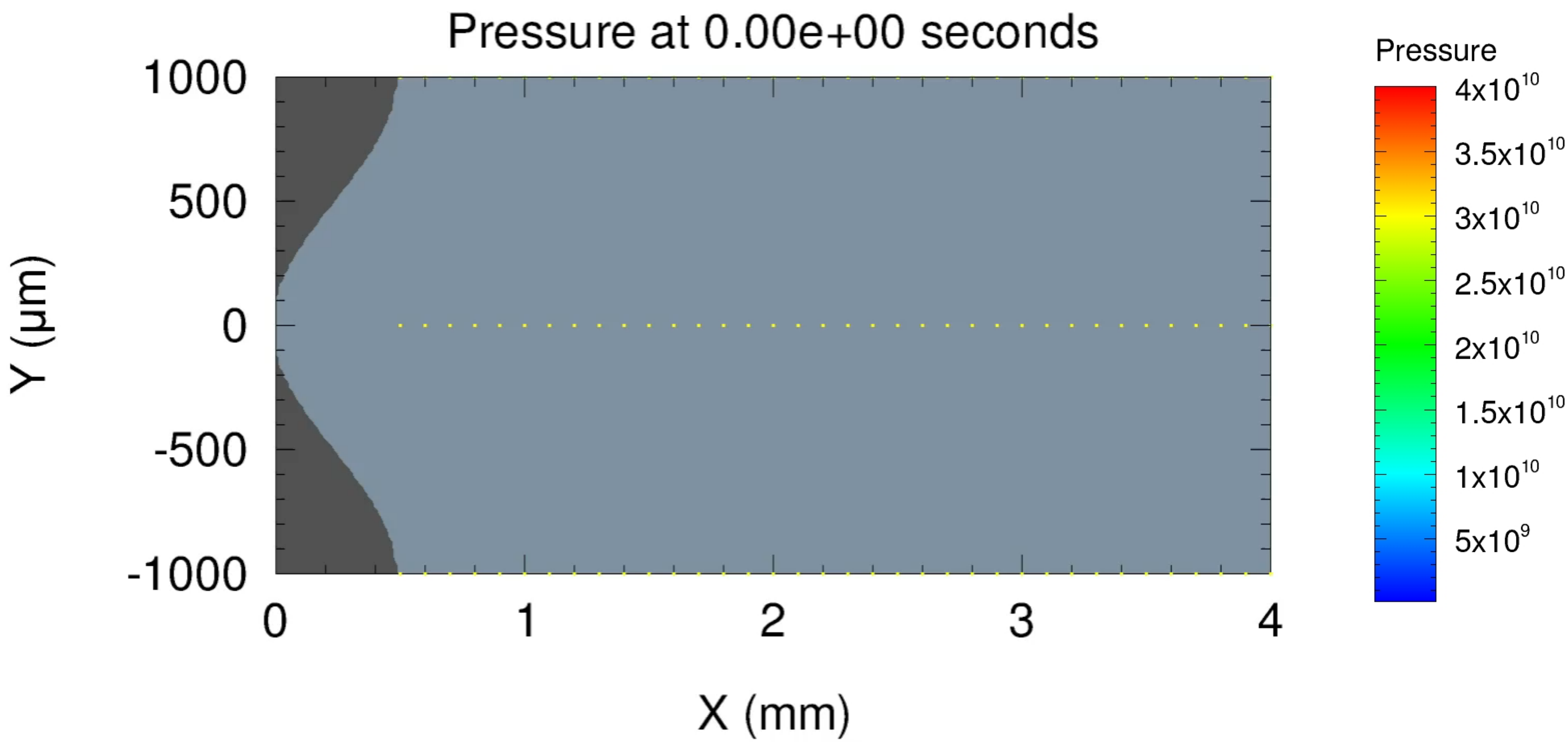


Continuum Simulations

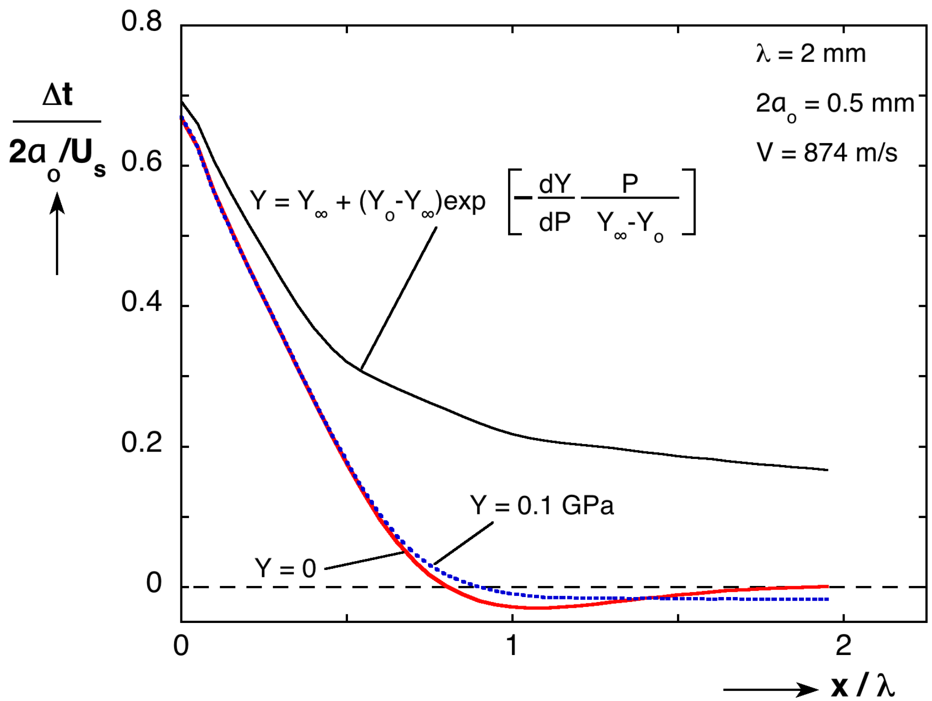
- performed with CTH
- symmetry BC at top and bottom
- aluminum impactor and driver with sinusoidal perturbation
- granular WC (gray) modeled with P-λ compaction description (calibrated to planar impact shots) and a strength model
- wave propagates in sample and perturbation decays
- interface distorts small amount but remains stable
- σ ~ 5 GPa for 874 m/s impact



Continuum Simulations

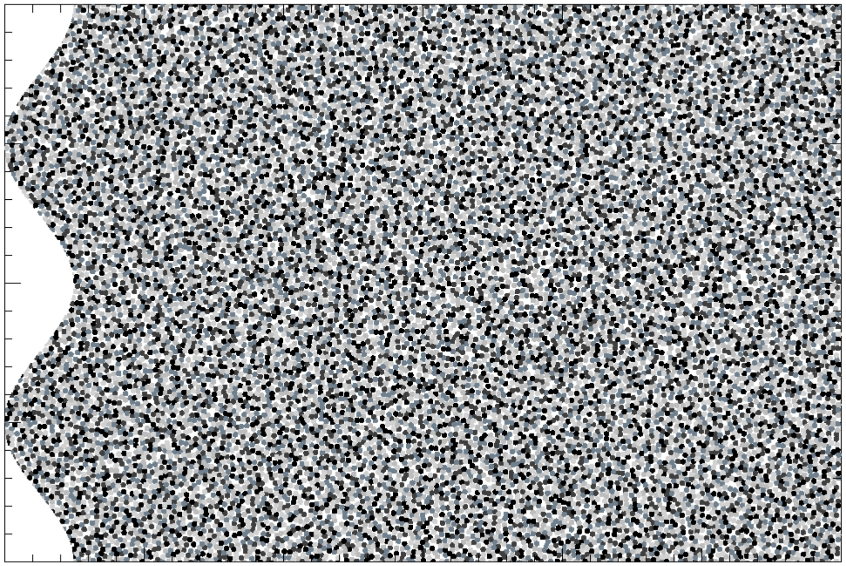


Continuum Simulation Results

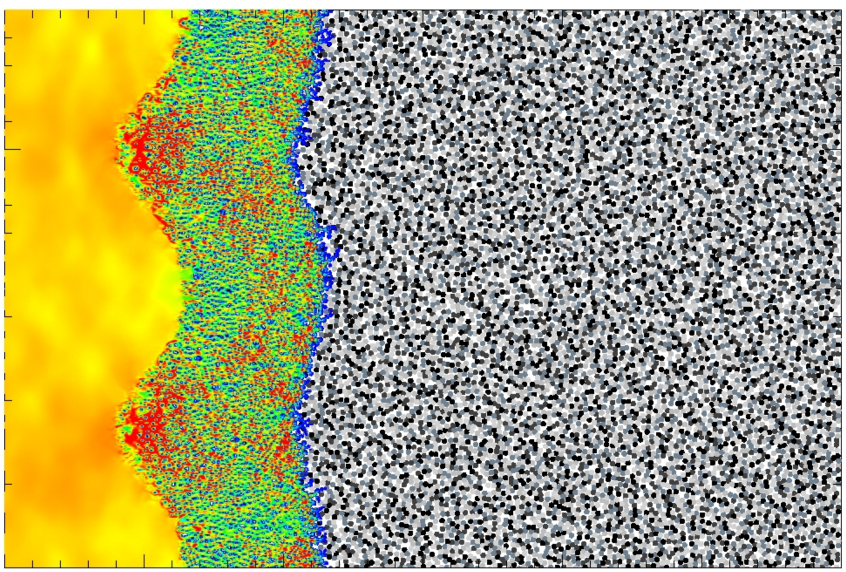


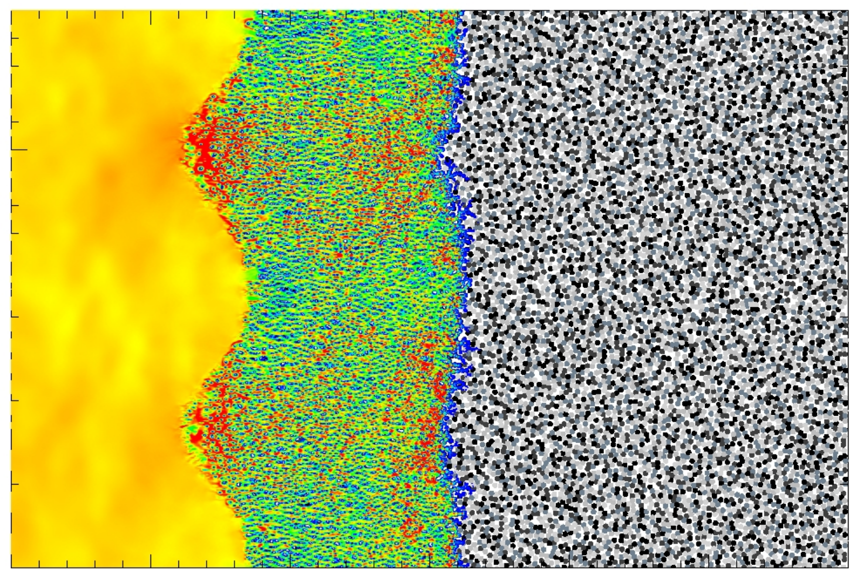
- consider three strength models:
  - Y=0
  - Y=0.1 GPa
  - pressure-dependent strength calibrated from pressure-shear data
- Y=0 case overshoots
- Y=0.1 GPa decays to ~0
- pressure-dependent strength maintains finite Δt to x>4 mm
- 2 – 4 mm is optimal for distinguishing models
- mesh refinement, artificial viscosity, and compaction law have minimal effect on results when Y=0.1 GPa

CTH Mesoscale Simulations

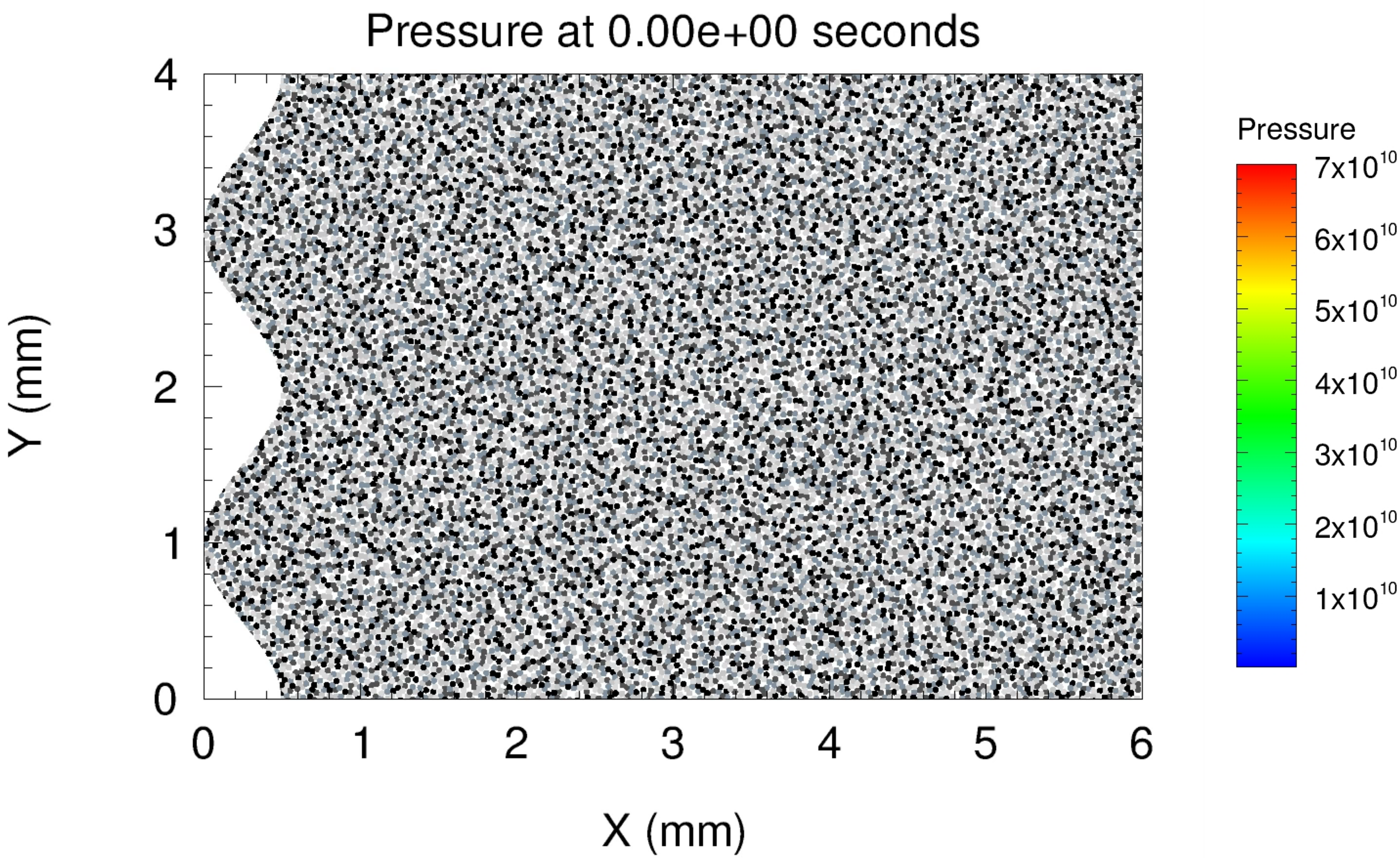


- 2-D mesoscale calculations similar to Borg & Vogler
- individual WC particles idealized as circles
- WC modeled with Mie-Gruneisen EOS and elastic-perfectly plastic strength

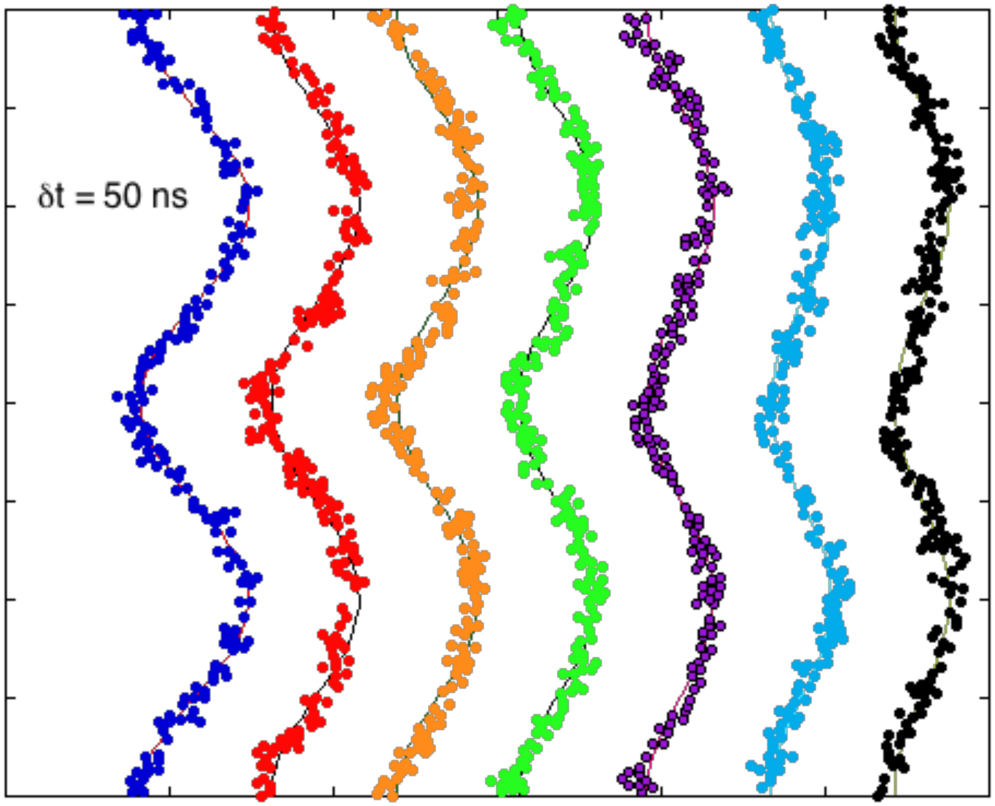




CTH Mesoscale Simulations

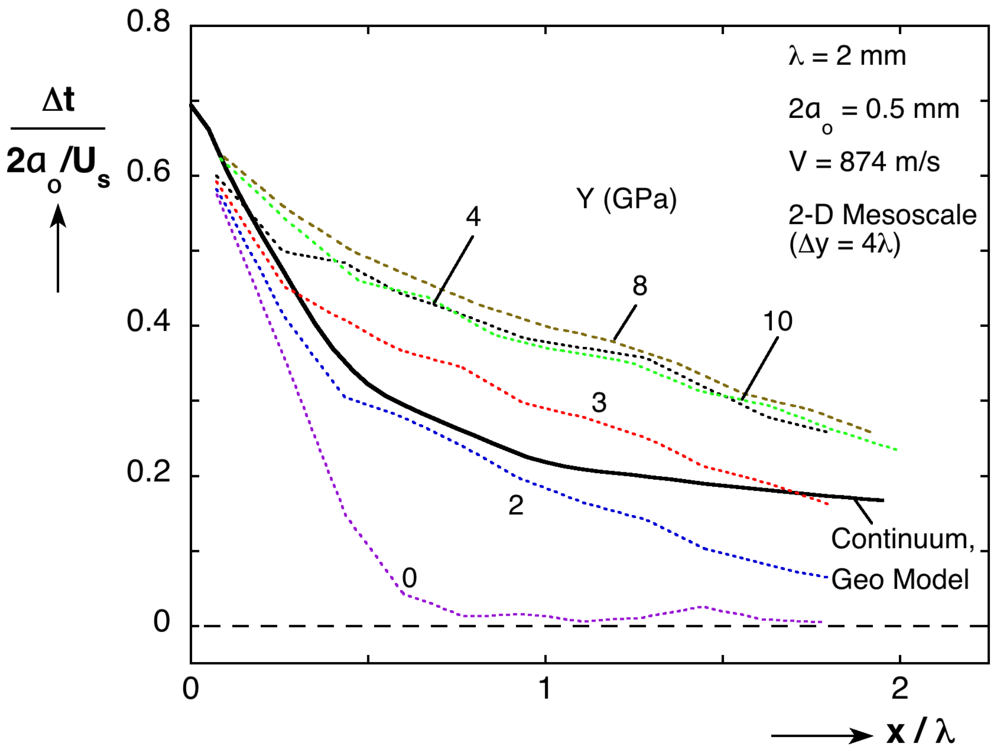


CTH Mesoscale Simulations: Data Extraction



- monitor when each particle reaches half of steady state velocity
- consider particles that reach this level for a given δt
- fit sine wave through resulting point to determine Δt of wave

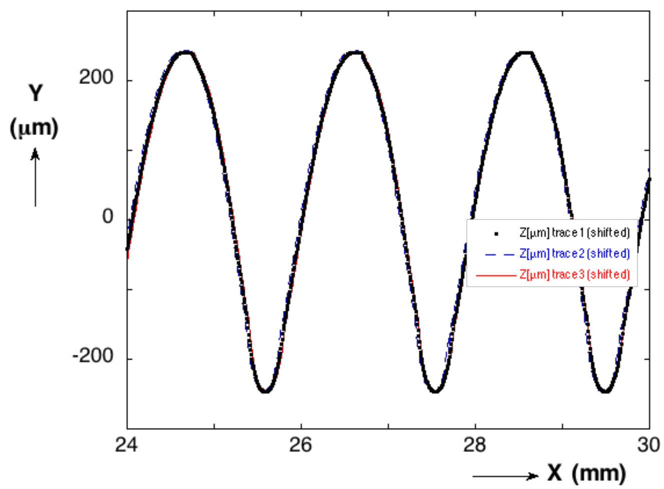
Decay in CTH Mesoscale Simulations

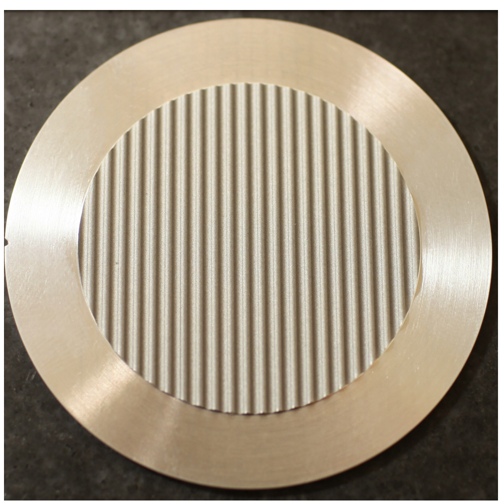


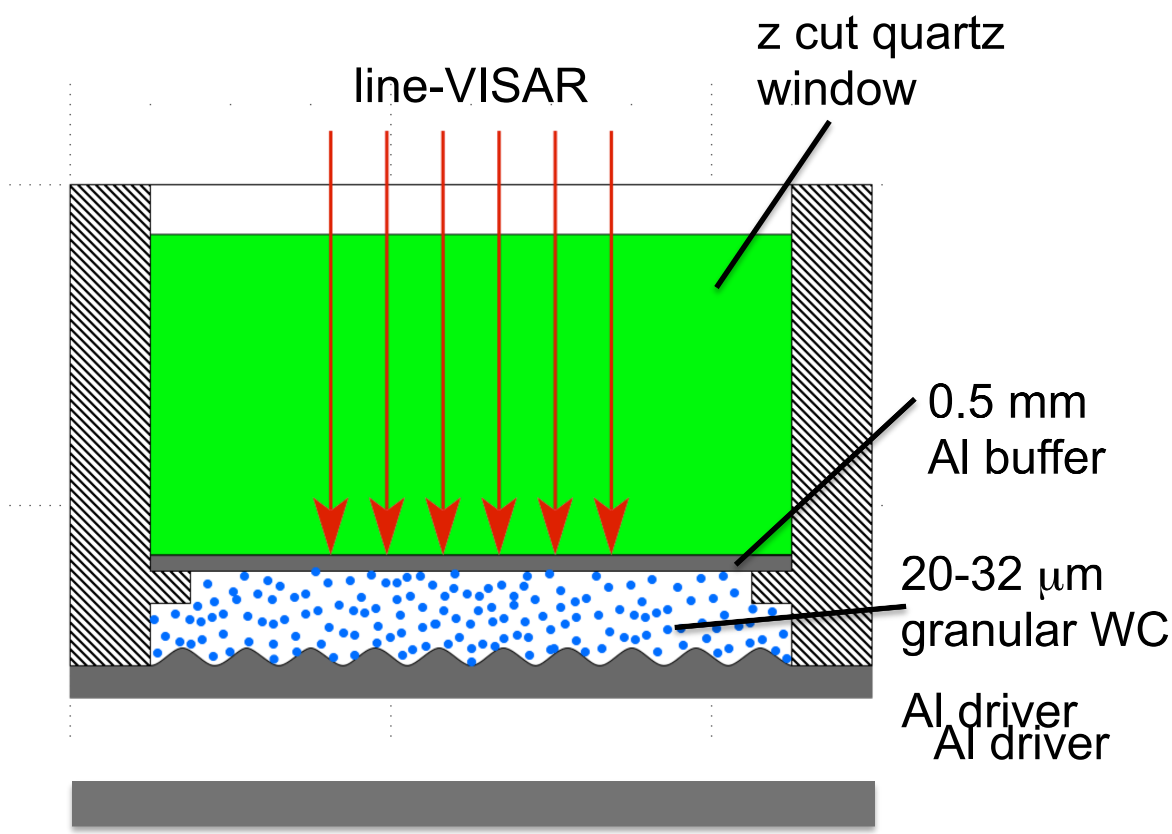
- mesoscale results dependent on strength; 2-D and 3-D very similar
- significant variability for different realizations, so $\Delta y = 4\lambda$
- need to explore sensitivity to other phenomena not in mesoscale calculations
  - interface treatment / friction
  - fracture
  - etc.

Experimental Configuration

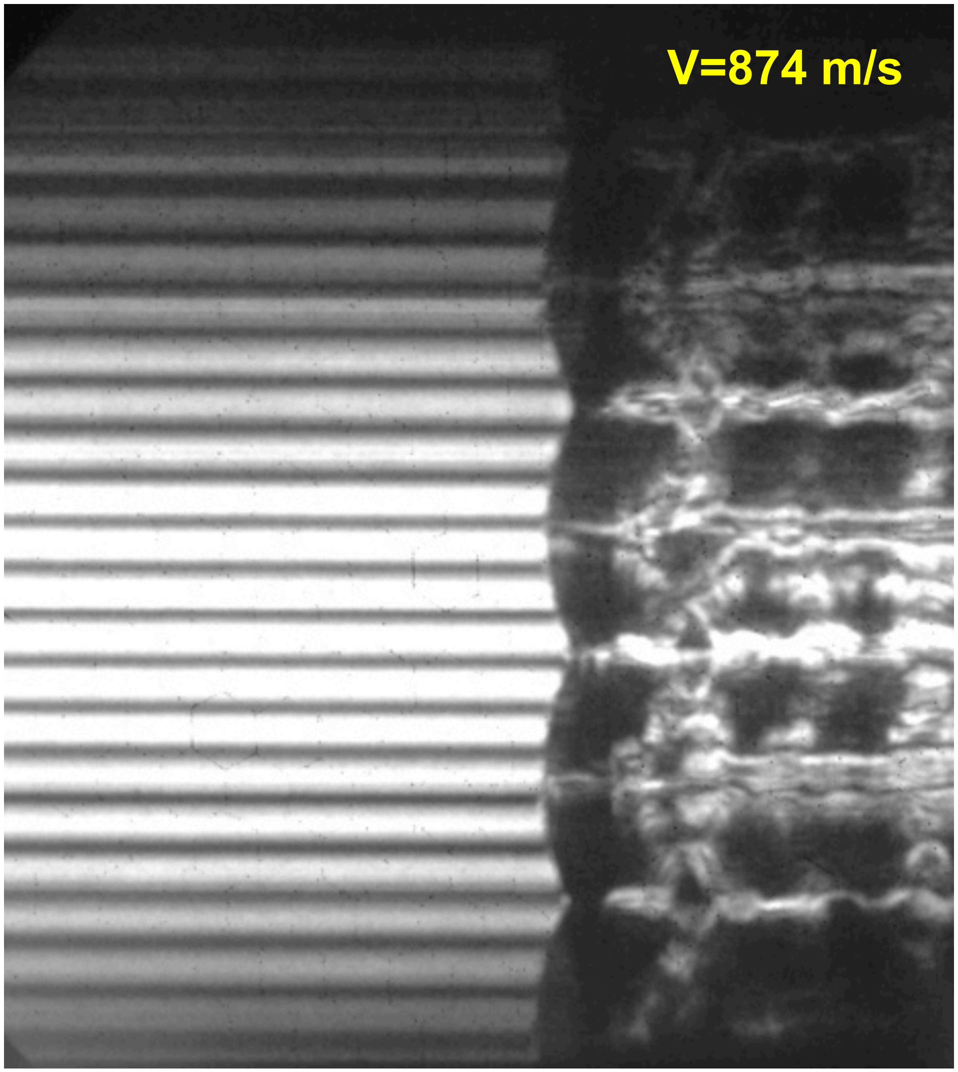
λ=2mm, 2a = 0.5 mm





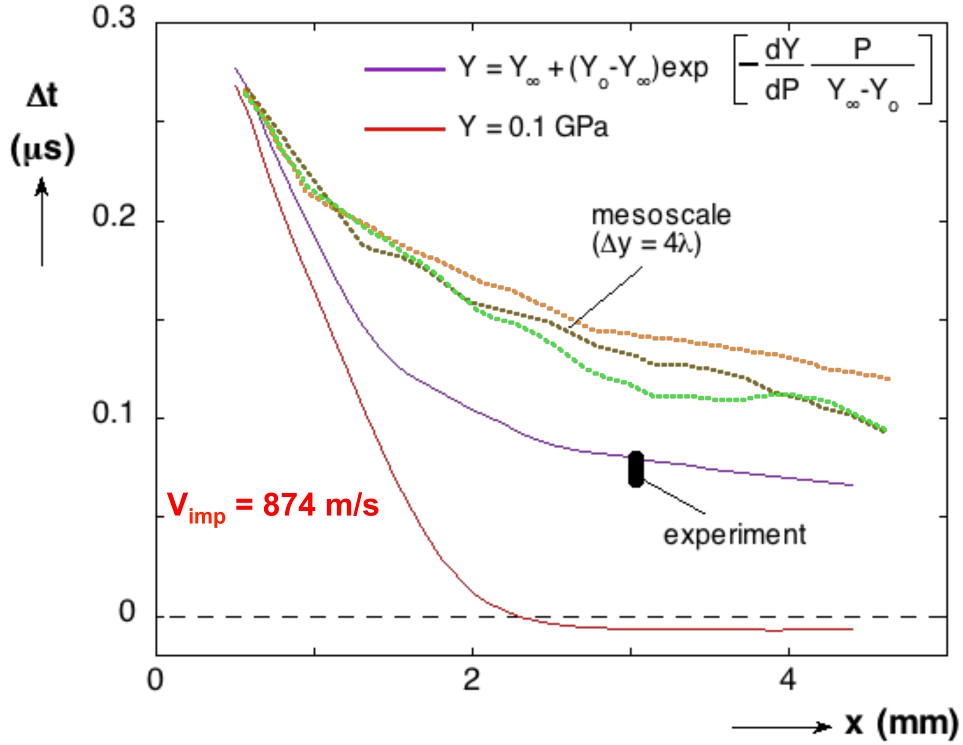


Perturbation Decay Measurement with Line-VISAR



- sample was 2.53 mm from top of perturbation to buffer
- perturbation of flow obvious; post-shock arrival difficult to interpret
- analysis approach simplistic
- will require large number of shots to populate perturbation decay plot

Experimental Results

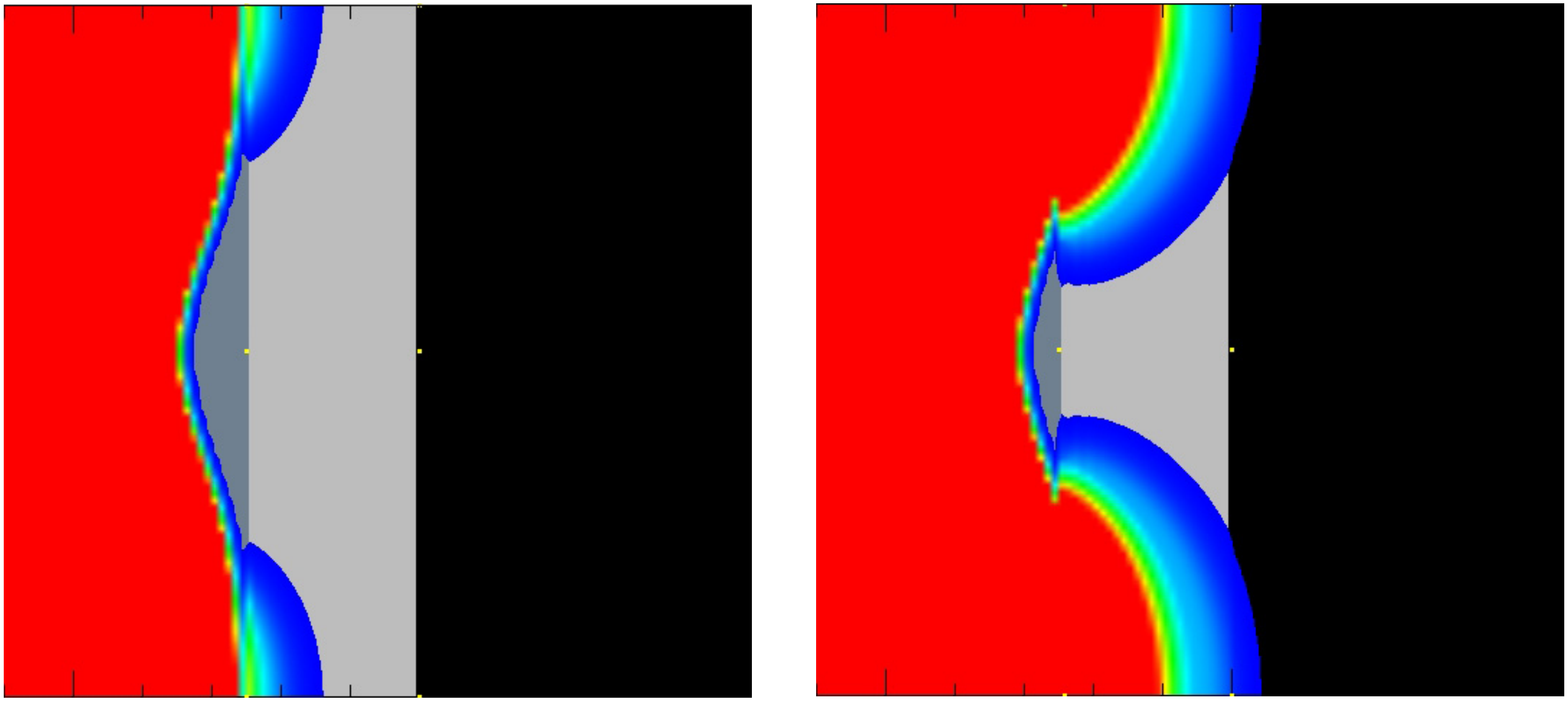


- experimental results appear similar to pressure-dependent model and below mesoscale
- additional data needed to better resolve behavior

But...

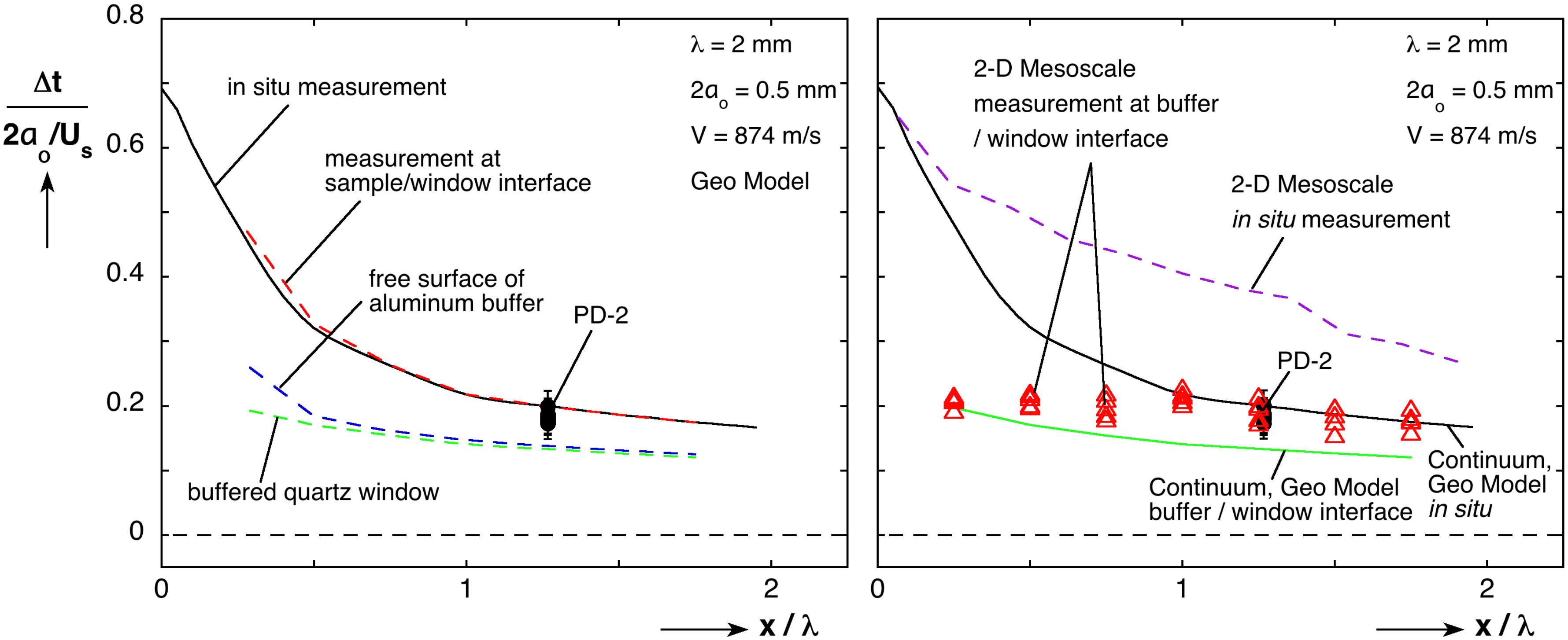
What about the buffer?

Buffer Strongly Distorts Measurements



- sinusoidal wave front entering Al buffer (faster wave speed) converges ahead of wave in granular sample

Buffer Strongly Distorts Measurements



- buffer makes wave appear to decay more rapidly
- experimental result agrees well with mesoscale simulations incorporating buffer/window, not as well with continuum calculations
- future experiments should minimize / remove buffer

Conclusions

- perturbation decay experiments appear capable of discriminating different strength behaviors for granular materials - increased strength delays perturbation decay
- initial experiments with line-VISAR are promising, but data return low; other approaches in development
- measurements strongly affected by Al buffer
- results at 874 m/s consistent with mesoscale model calibrated to compaction results
- alternate formulations for mesoscale model may provide additional insight