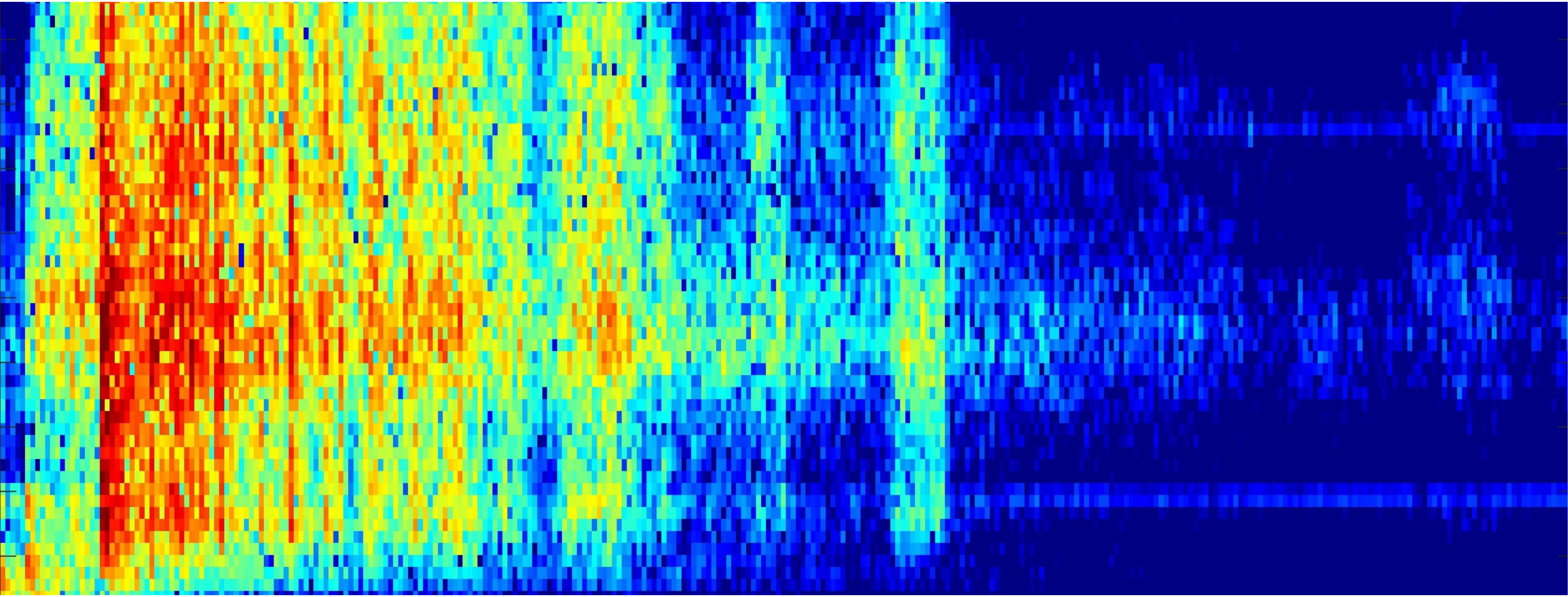
Deciphering seismic and normal-force fluctuation signatures of debris flows: an experimental assessment of effects of flow composition and dynamics



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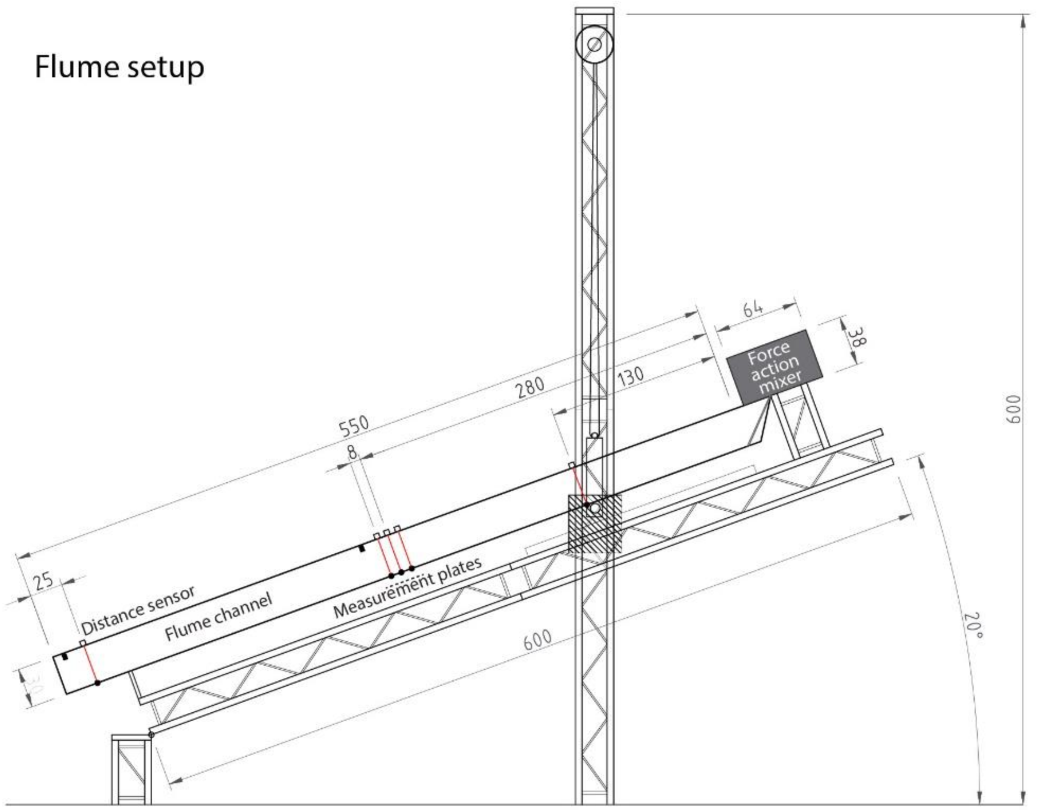
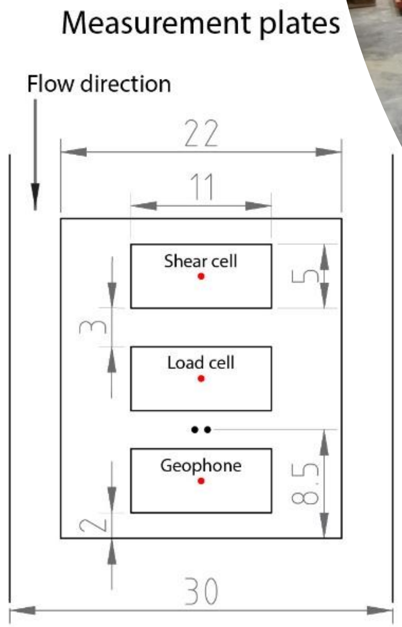
Research questions

- How do the seismic vibrations and normal-force fluctuations induced by debris flows relate?
- How do debris-flow composition and volume affect seismic vibrations and normal-force fluctuations?
- To what extent can debris-flow dynamics and composition be inferred from the seismic vibrations and normal-force fluctuations of a debris flow?

Flume setup

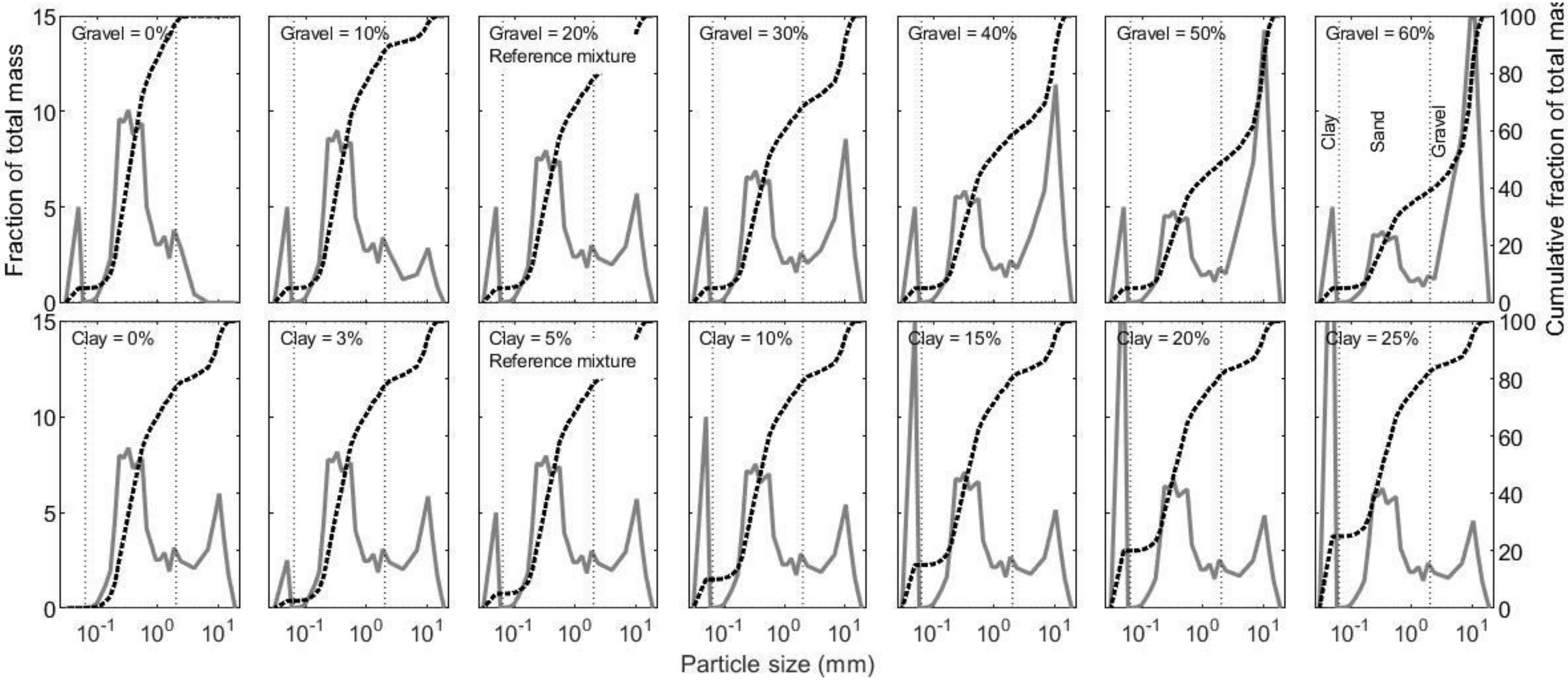
Force plate and geophone plate mounted in the channel



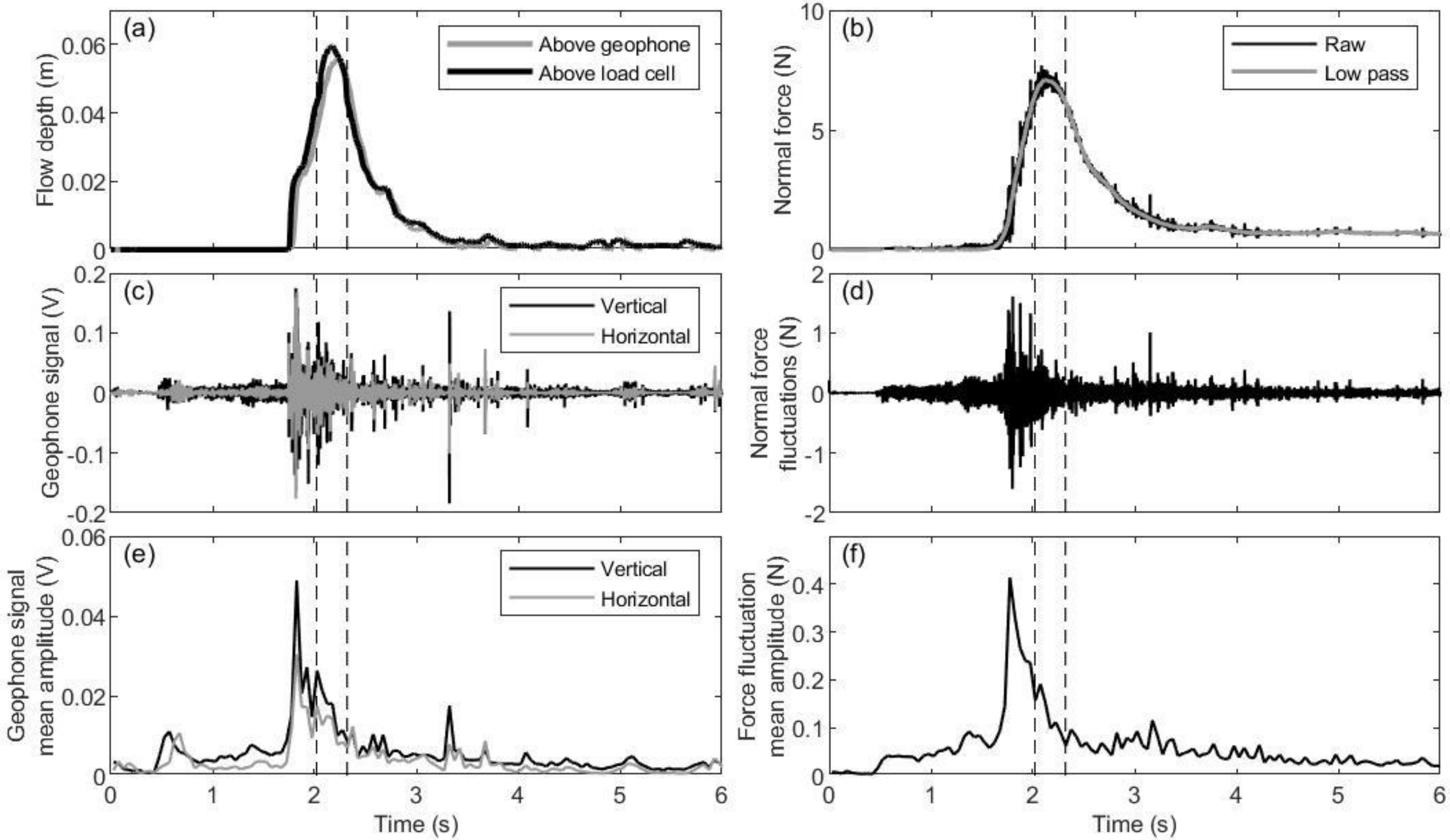


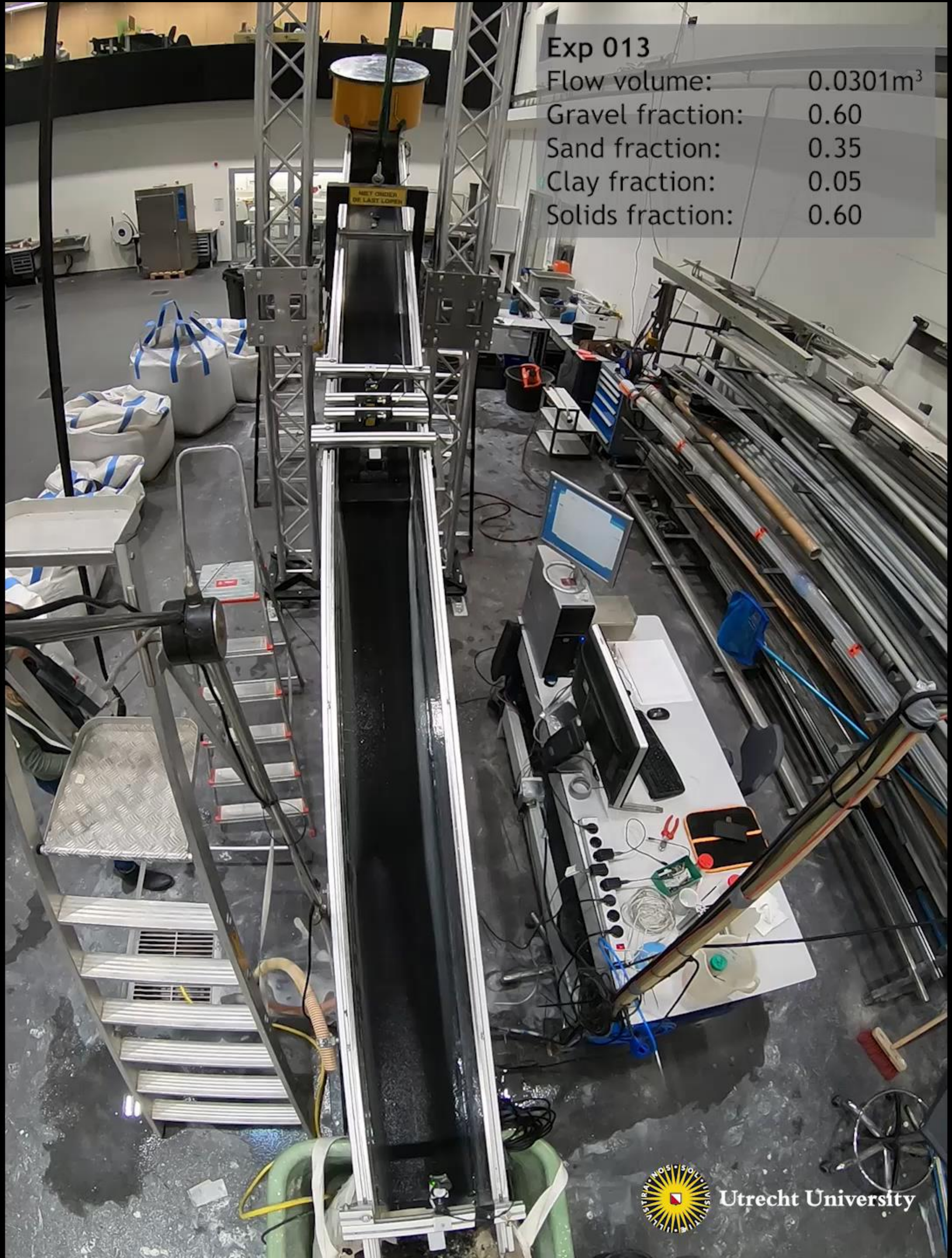
Grain size distributions

Mixtures of gravel, sand, and clay, leading to trimodal grain-size distributions



Derivation of fluctuating forces




Exp 013
Flow volume: 0.0301m³
Gravel fraction: 0.60
Sand fraction: 0.35
Clay fraction: 0.05
Solids fraction: 0.60
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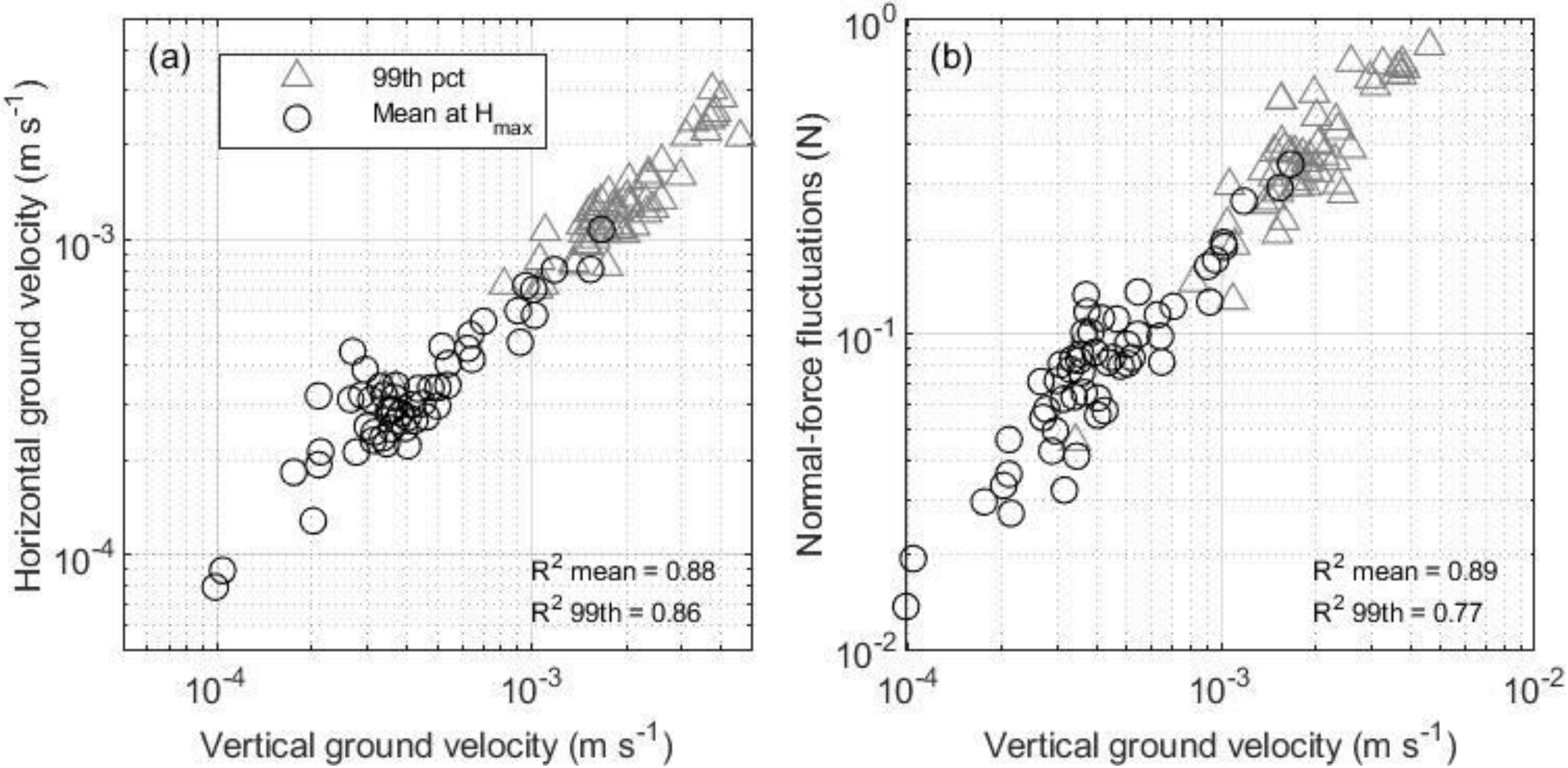
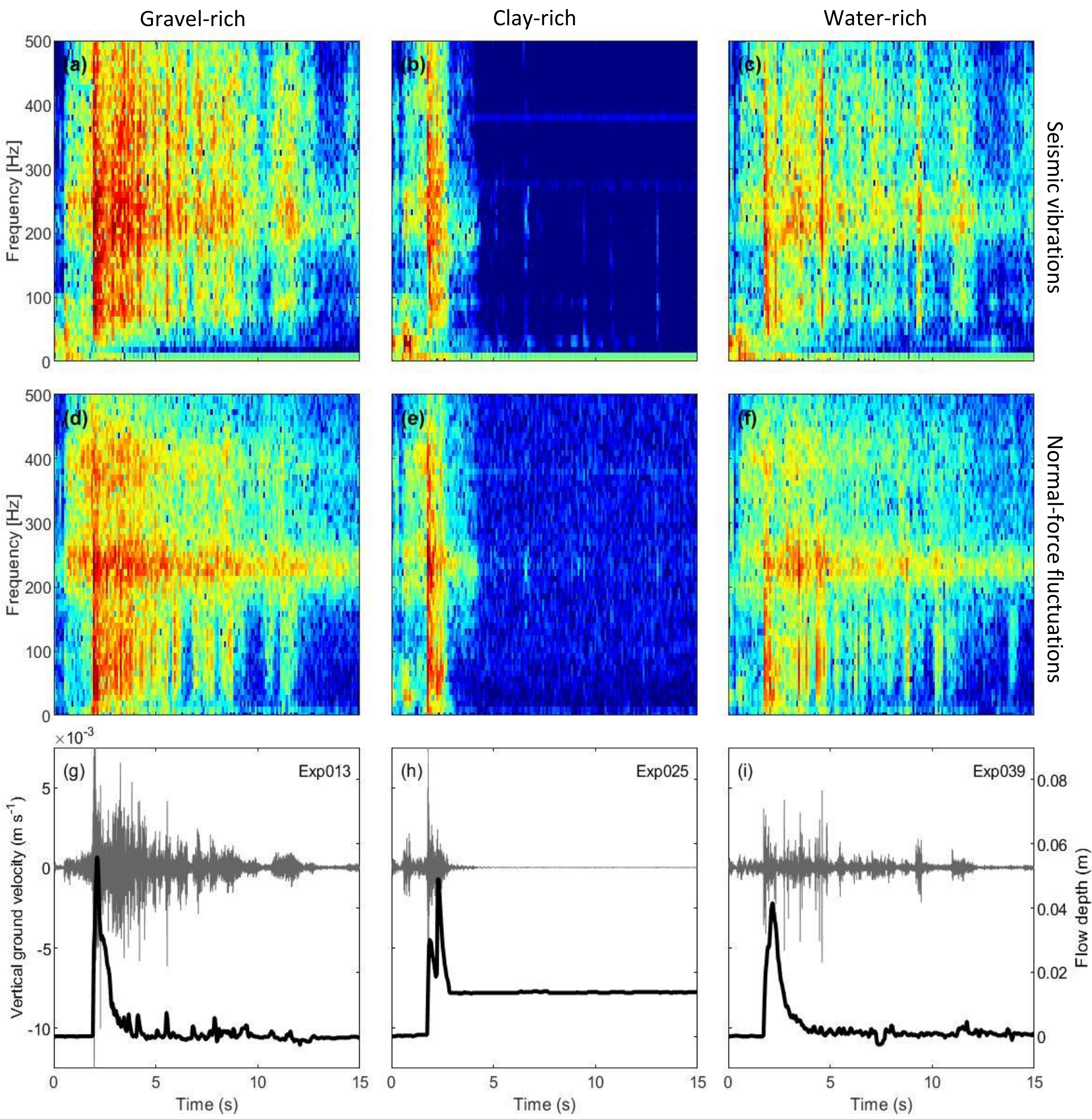
Strong correspondence between seismic vibration and normal-force fluctuations

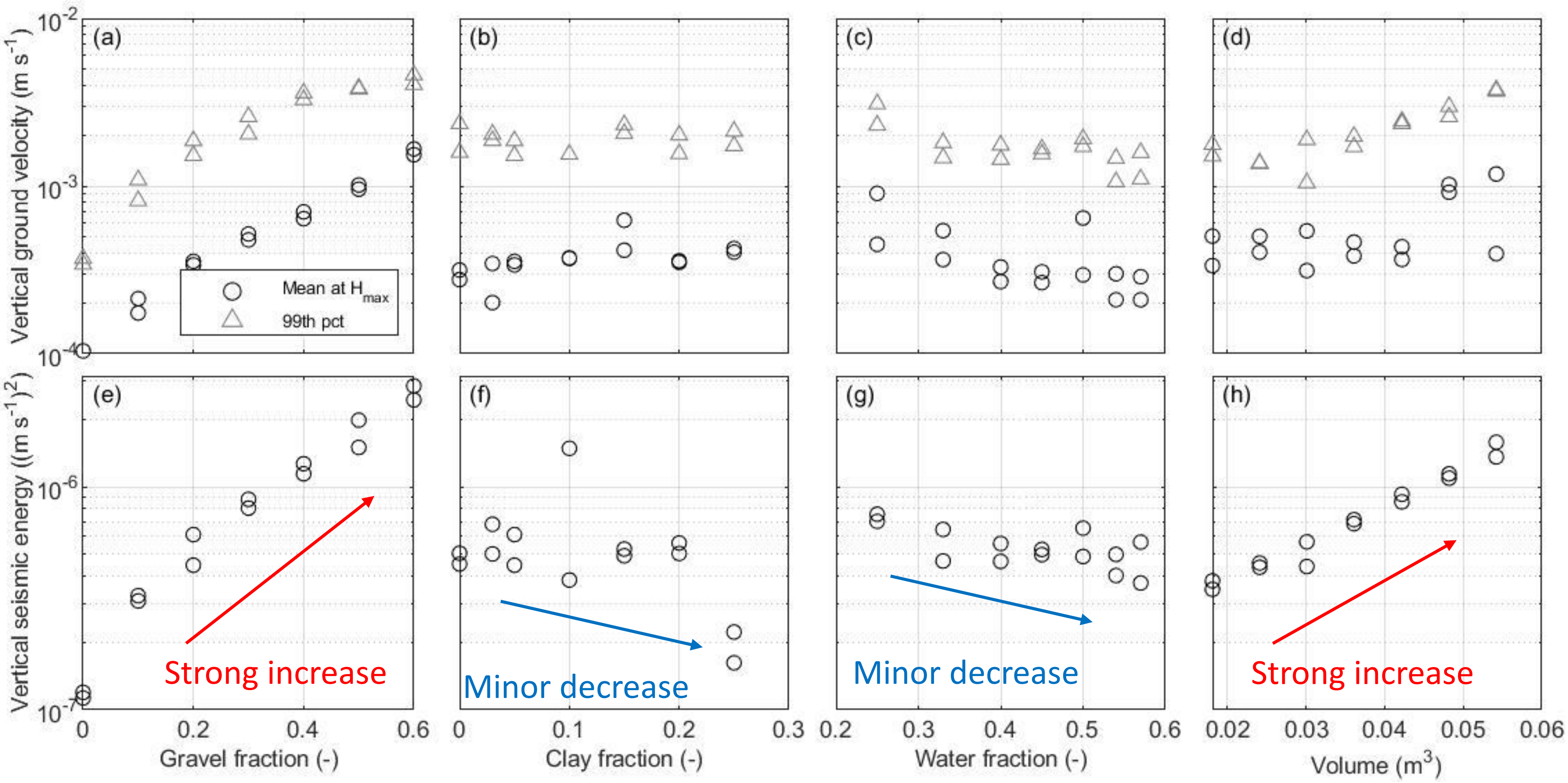


Power spectra

- Main frequency 200-300 Hz
- Higher than measured in natural torrents because of:
  - Limited path effects
  - Stainless steel flume material
- Spectrograms of seismic vibrations and normal-force fluctuations very similar
- Strong effect of flow composition

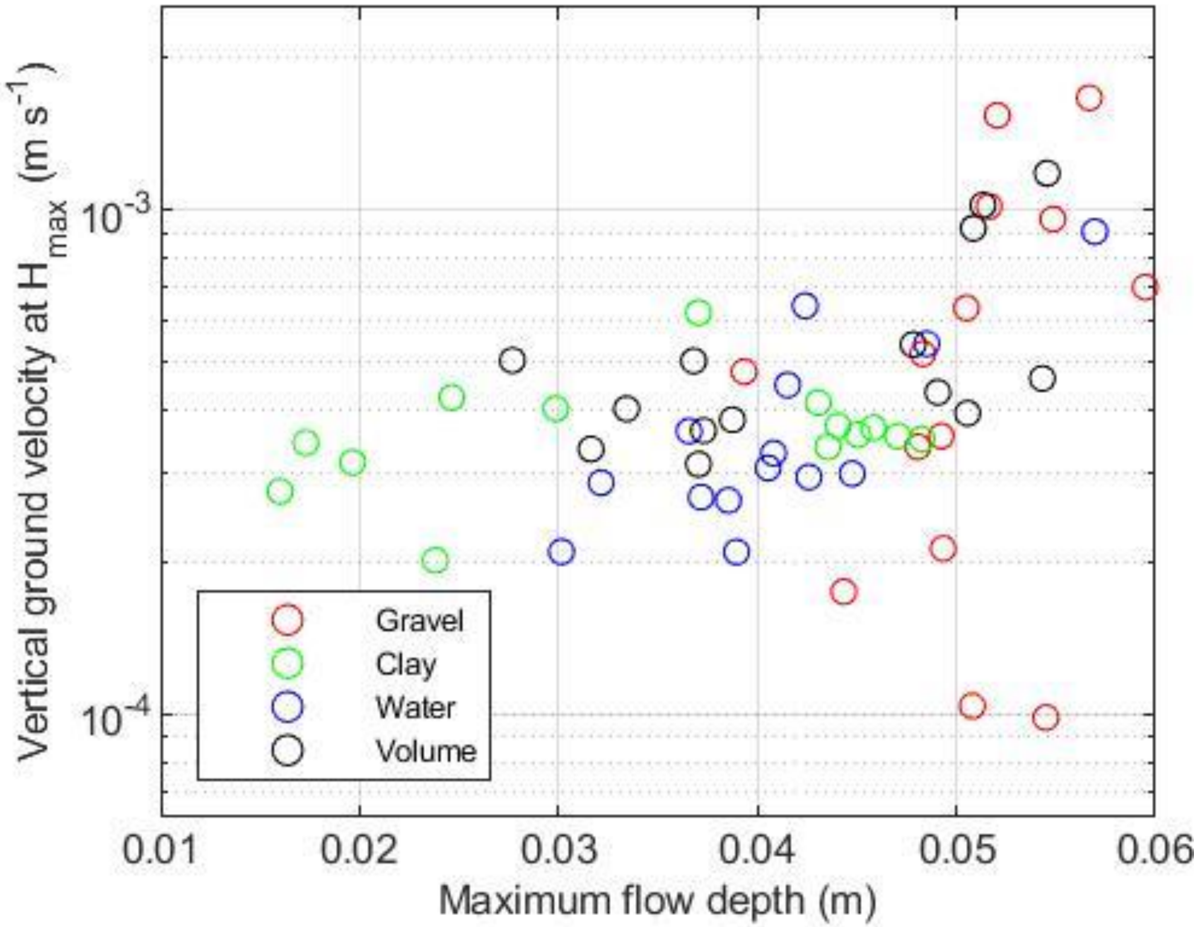


Effects of flow composition on vertical ground velocity and seismic energy



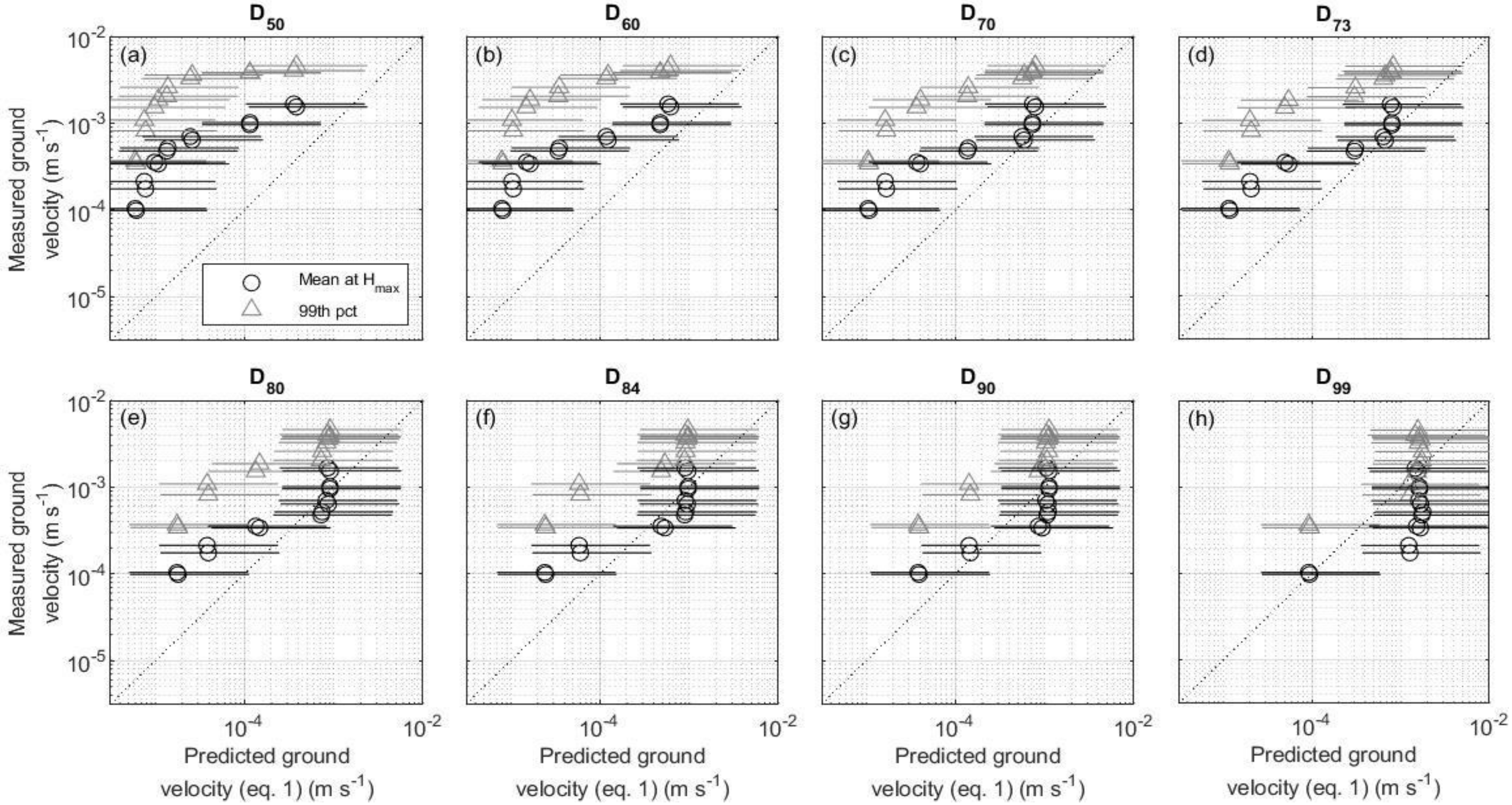
Flow depth vs vertical ground velocity

- Reasonable trend between flow depth and ground velocity
  - But not where gravel (large particle) fraction substantially varies
- The effect of large-particle distribution outweighs the effect of flow depth



Reasonable correspondence between ground velocity and $u^{1.5}{D_e}^{1.5}$

$$\textbf{eq. 1}: \ \boldsymbol{iGVS} \propto \bar{\boldsymbol{u}}^{1.5}{\boldsymbol{D_e}}^{1.5}\boldsymbol{W}^{0.5}(1+\boldsymbol{e_b})\boldsymbol{\phi}^{0.5}$$



Farin et al. (2019)

u = flow velocity

D_e = effective grain size

Conclusions

(1) The large-particle distribution dominates seismic vibrations and normal-force fluctuations.

(2) An increase in large particles (gravel in our experiments) leads to a strong increase in the magnitude of ground velocities and normal-force fluctuations.

(3) An increase in water fraction (i.e., decrease in sediment concentration) leads to a subtle decrease in the magnitude of ground velocities and normal-force fluctuations.

(4) Clay fraction does only marginally affect ground velocities and normal-force fluctuations.

(5) An increase in flow volume leads to an increase in the magnitude of ground velocities and normal-force fluctuations.

(6) For flows with similar large-particle distributions seismic vibrations and normal-force fluctuations may be reasonably-well related to flow depth, even if total flow volume, water fraction, and the size-distribution of fines varies.

(7) There is a non-linear relationship between flow volume and seismic energy for flows of similar composition.

(8) These findings suggest that, within certain limits of flow composition, it may be possible to extract large-particle distribution, water fraction, flow depth, and flow volume from seismic or normal-force measurements.

Bonus slide: Flow composition vs flow velocity and depth