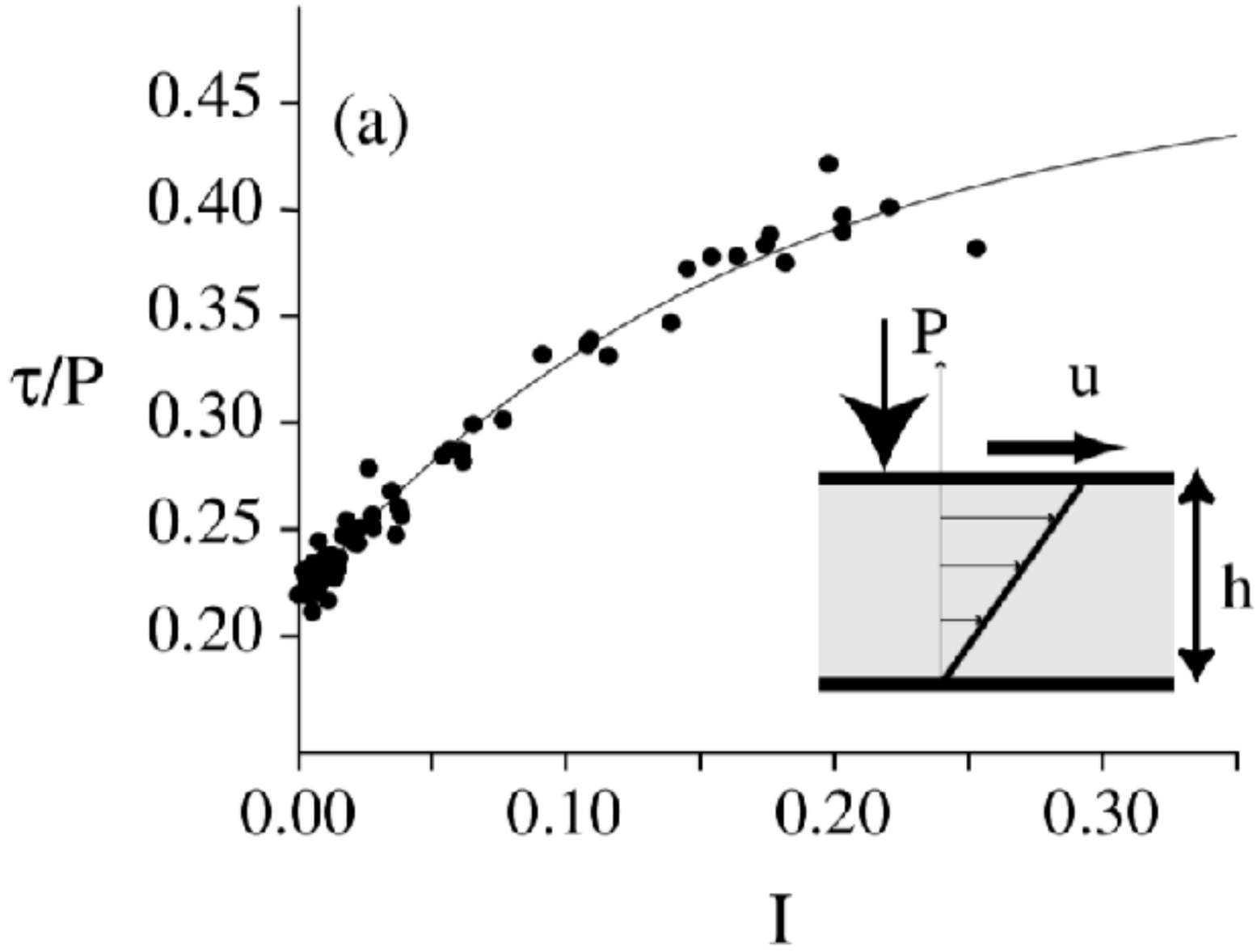
LARGE FRICTIONAL DRAG BY SHEAR-INDUCED SOLIDIFICATION OF GRANULAR LAYER

T. FURUTA, S. KUMAR, K. ANKI REDDY, H. NIIYA,
H. KATSURAGI
DEPT. EARTH & ENVIRON. SCI., NAGOYA UNIV.
CENTER FOR TRANSDISCIPLINARY RESARCH, NIIGATA UNIV.
DEPT. CHEM. ENG., IIT GUWAHATI, INDIA

GRANULAR FRICTION

PREVIOUS STUDIES ON $\mu - I$ RHEOLOGY



$$\tau = P\mu(I)$$

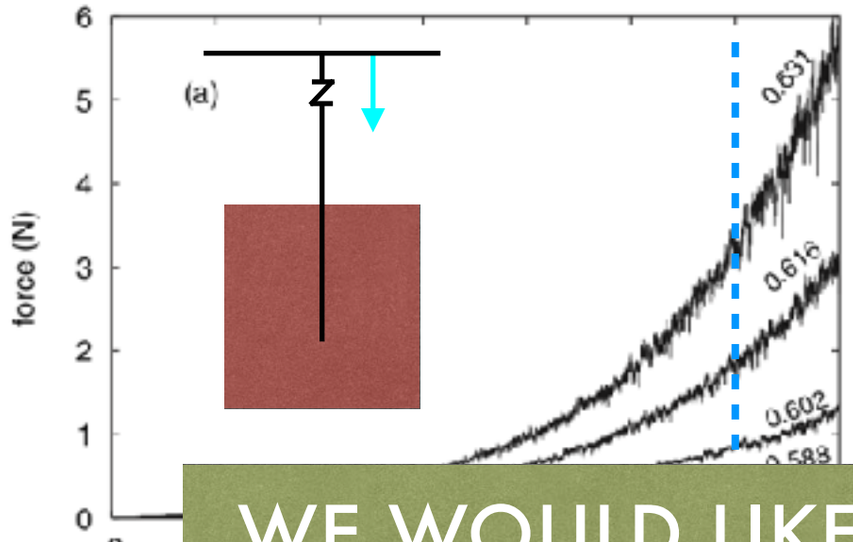
$$I = \frac{\dot{\gamma} d}{\sqrt{P/\rho_p}}.$$

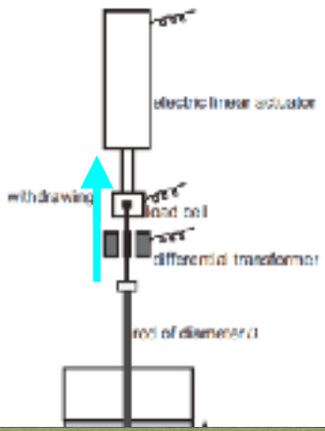
$$\mu(I) = \mu_s + \frac{\mu_2 - \mu_s}{I_0/I + 1}$$

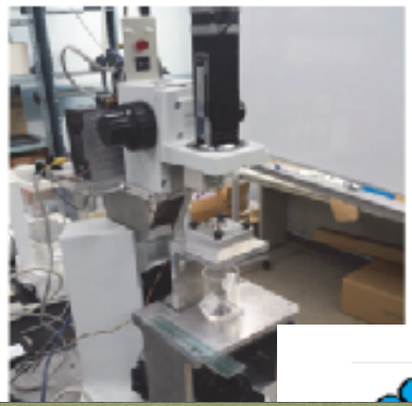
Pouliquen et al., JStatMech P07020 (2006)

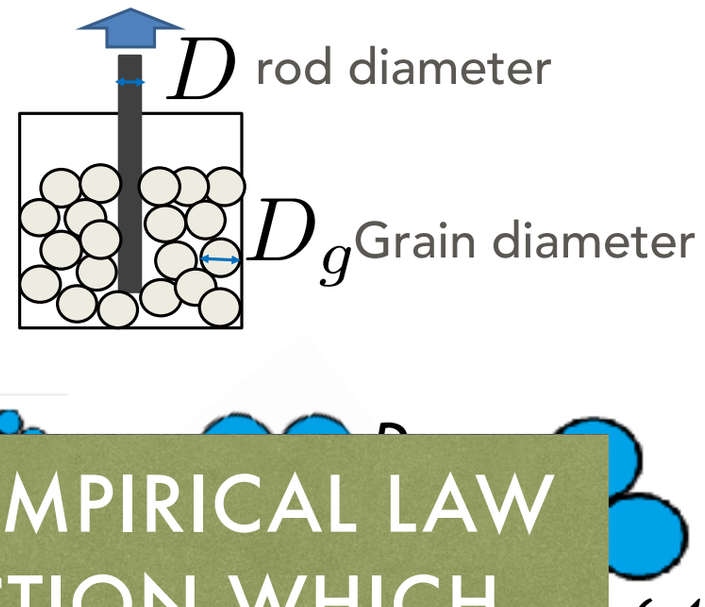
PENETRATION AND WITHDRAWING

WITH GRANULAR FRICTION

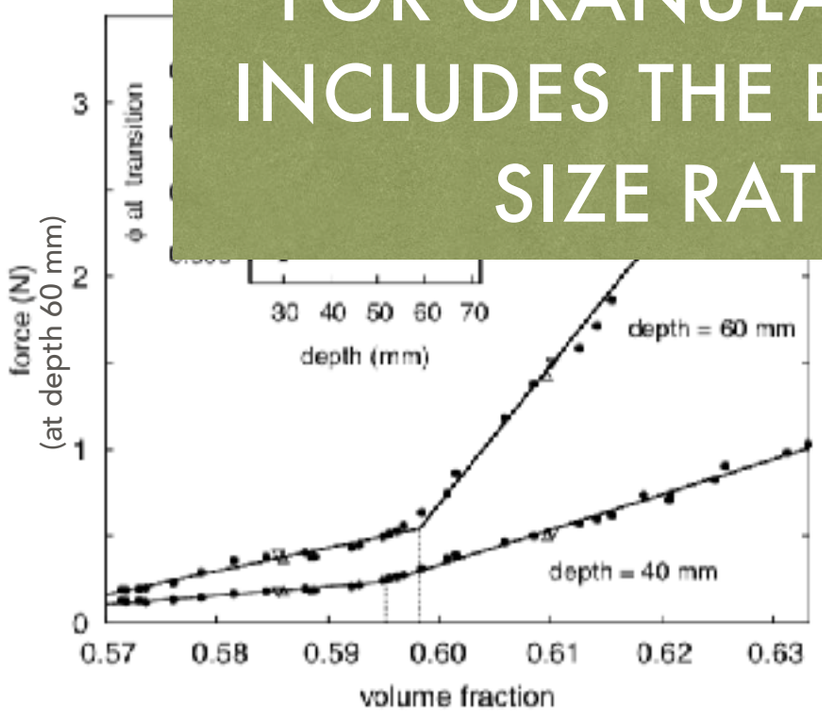




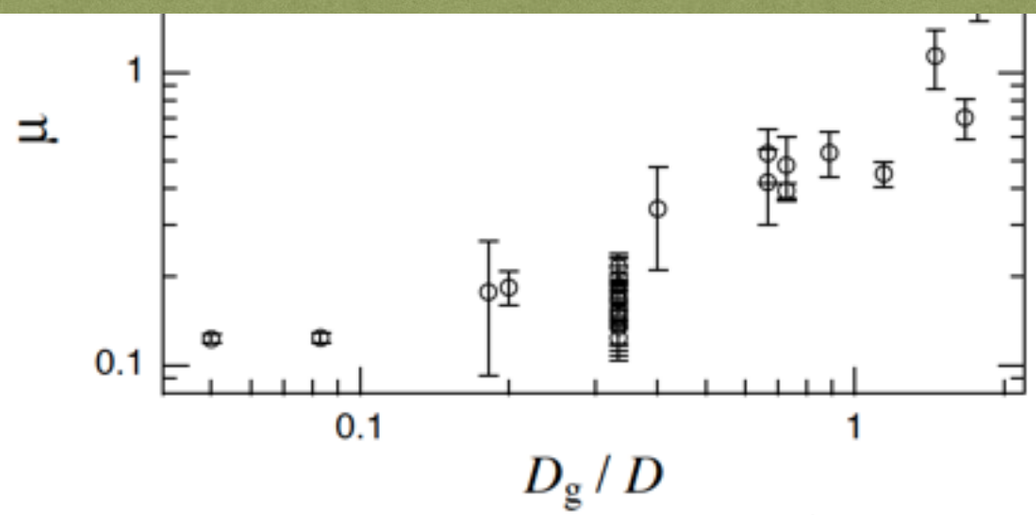




WE WOULD LIKE TO CONSTRUCT AN EMPIRICAL LAW FOR GRANULAR WITHDRAWING FRICTION WHICH INCLUDES THE EFFECTS OF PACKING FRACTION AND SIZE RATIO BETWEEN GRAIN AND ROD



Schröter et al., EPL 78, 4404 (2007)

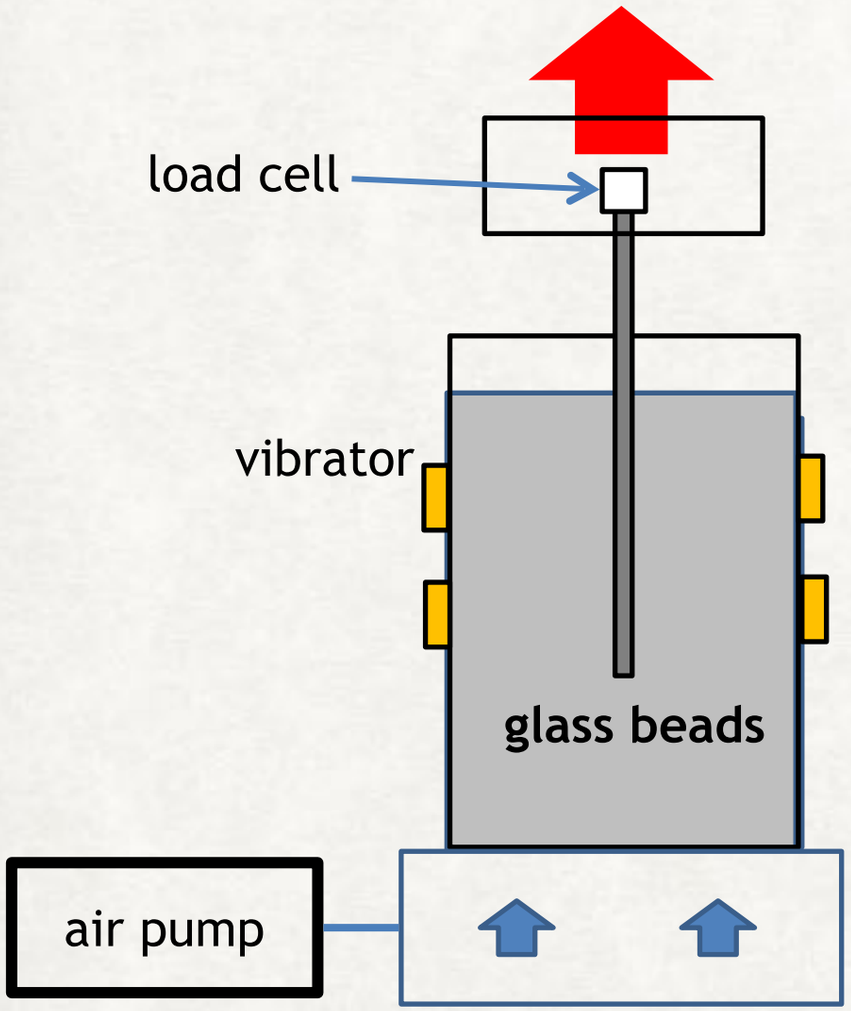


Furuta et al., IJMPB 31, 1742006 (2017)

EXPERIMENTAL SETUP

PROTOCOL & MATERIALS

Setup:



Protocol:

1. Preparing a glass beads layer
2. Making a porous granular layer by air fluidization
3. Controlling a compaction degree by vibration
4. Measuring packing fraction
5. Withdrawing a rod and measuring force

Parameters:

Grain diameter: $D_g = 0.4\text{-}2.0$ mm

Rod diameter: $D = 0.3\text{-}3.2$ mm

Size ratio: $D_g/D = 0.13\text{-}2.7$

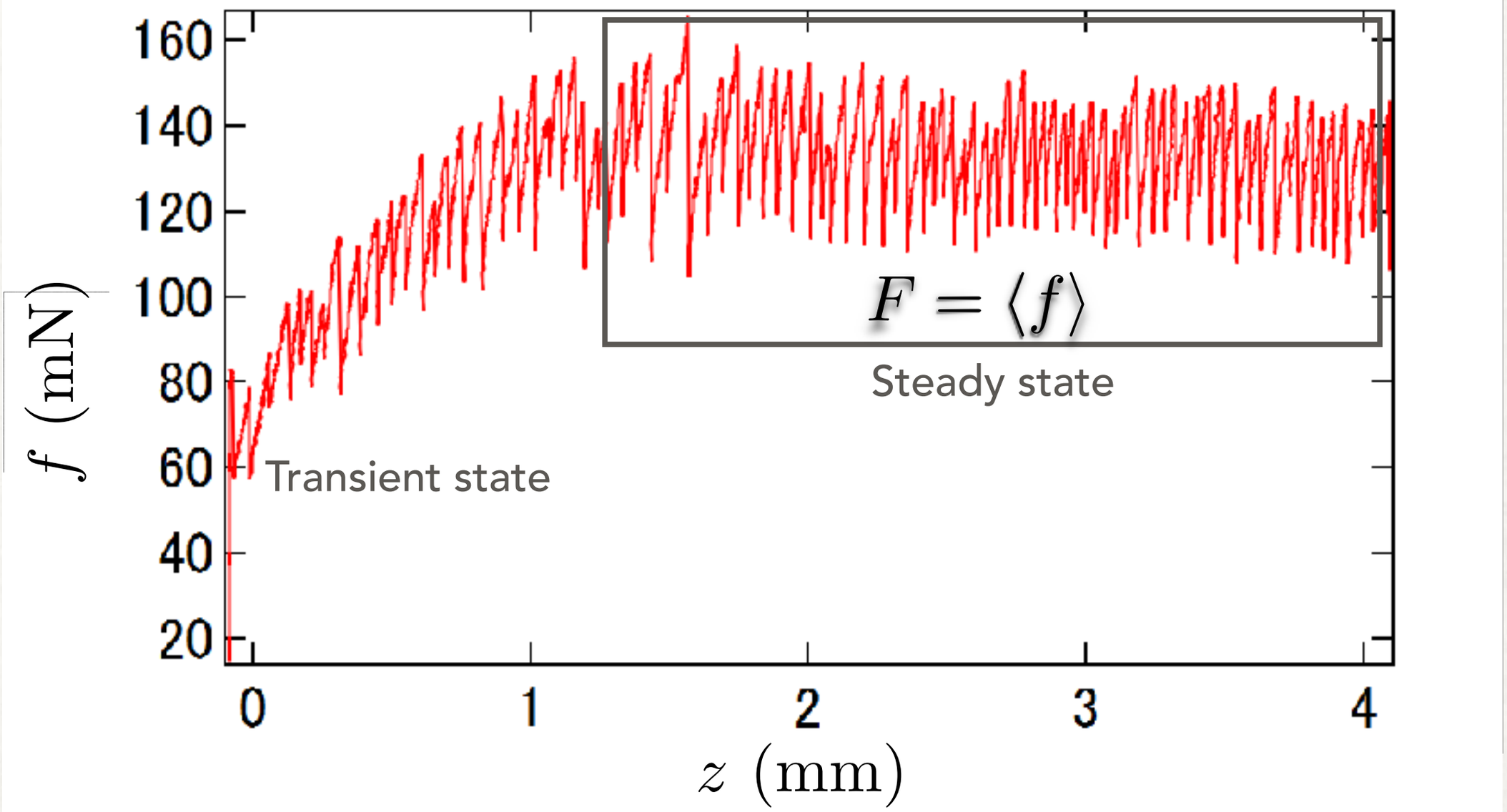
Packing fraction: $\phi = 0.58\text{-}0.62$

Vessel diameter: 51 mm

Initial buried depth: 45 mm

RAW DATA OF FRICTION FORCE

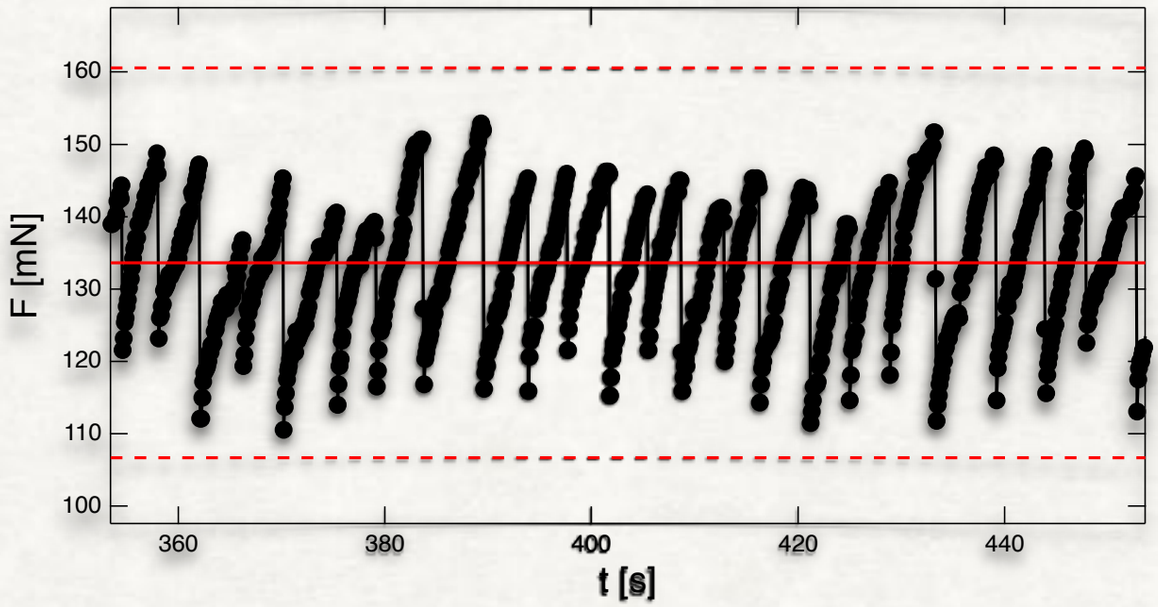
IN STEADY STATE

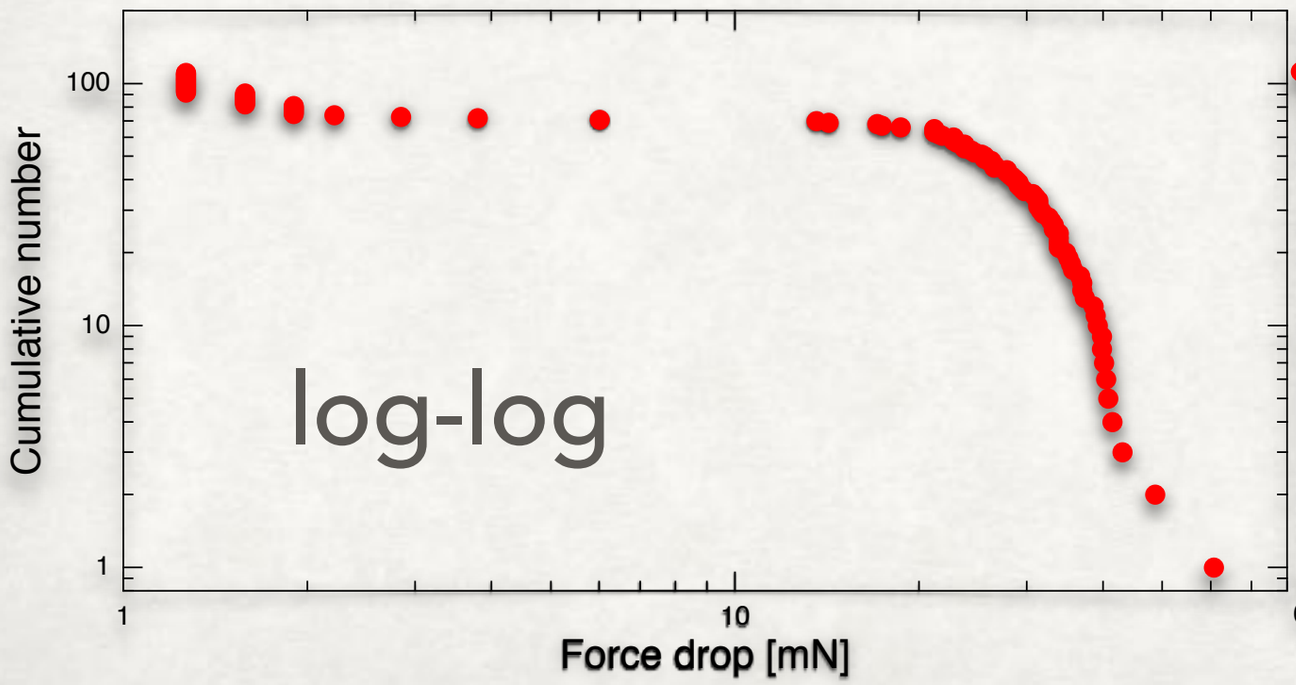


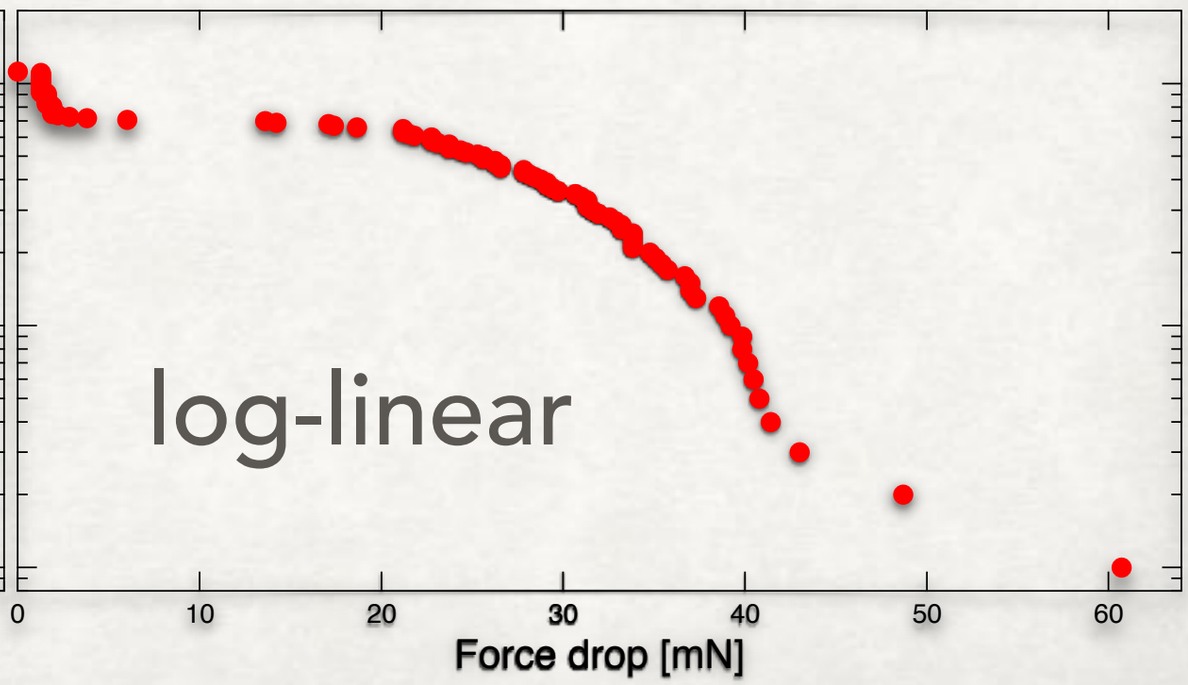
$D_g/D = 1.5 \quad \phi = 0.61$

SIZE DISTRIBUTION OF FORCE DROPS

(IN STEADY REGIME)

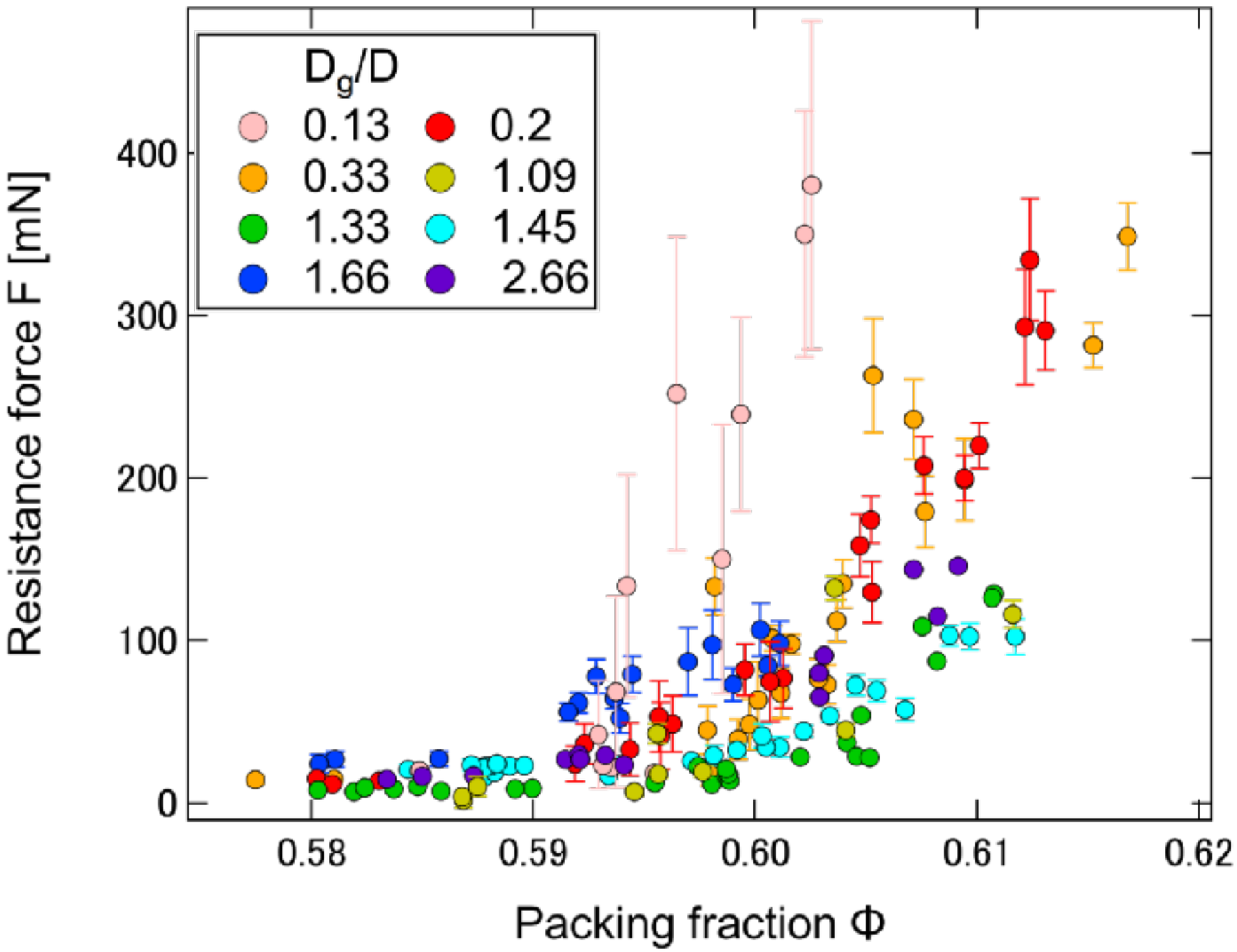






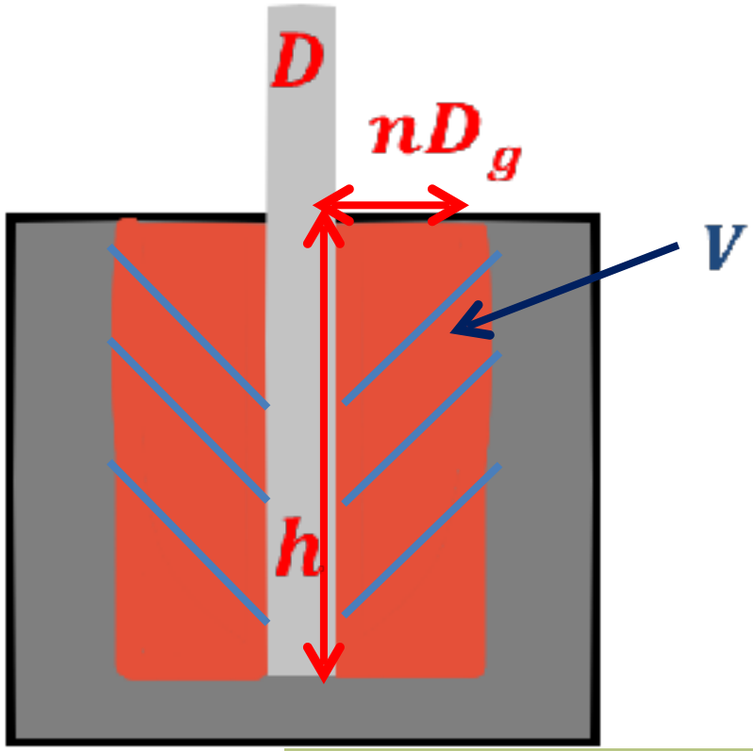
FORCE VS PACKING FRACTION

IN STEADY STATE



SOLIDIFIED NORMAL FORCE MODEL

BY SHEAR JAMMING



$$F = \mu N$$

$$F = \mu\kappa\rho g V$$

$$\mu' = \mu\kappa \simeq 0.18 \times 0.5 \simeq 0.1$$

glass - stainless friction
(San Jose delta Inc.)

κ : Janssen parameter

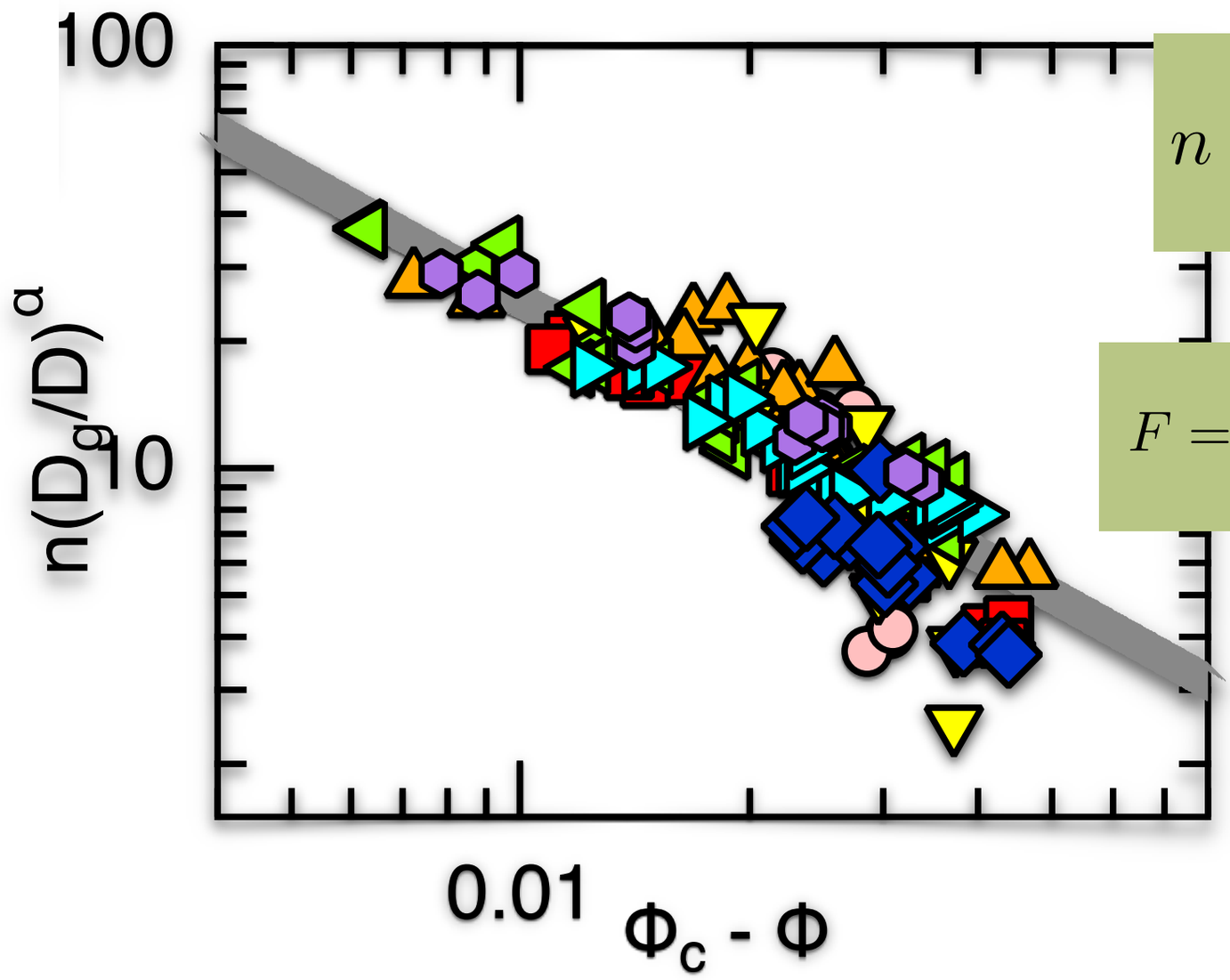
$$F = \mu'\rho g h \pi \left[\left(nD_g + \frac{D}{2} \right)^2 - \left(\frac{D}{2} \right)^2 \right]$$

$$n = \frac{-AD + \sqrt{(AD)^2 + 4AF}}{2AD_g}$$

$$A = \mu'\rho g h \pi$$

DATA COLLAPSE

CRITICAL DIVERGENCE



$$n\left(\frac{D_g}{D}\right)^{-\alpha} = n_0\left(\phi_c - \phi\right)^{-\beta}$$

$$F = \mu' \rho g h \pi \left[\left(nD_g + \frac{D}{2}\right)^2 - \left(\frac{D}{2}\right)^2\right]$$

$$n_0 = 0.35$$
$$\phi_c = 0.62$$
$$\alpha = 0.56$$
$$\beta = 1.3$$

4 fitting parameters,
but 2 or 3 are (hopefully) universal…

SUMMARY

- The empirical granular friction law for withdrawing an object from a relatively porous granular layer was experimentally obtained.
- From the experimental and numerical results, a shear-induced solidification could be triggered by the withdrawing.
- Using the obtained empirical law, we can easily estimate the granular frictional resistance force in various situation including probe extraction from regolith layer.