Predicting CSD Spillage

A pseudo-analytical model for spillage due to rotational velocity-induced flow

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Safety Moment

THE UNIVERSITY OF CHICAGO

Workers far away from windows during work hours

"slept an average of 46 minutes per night less during the workweek"

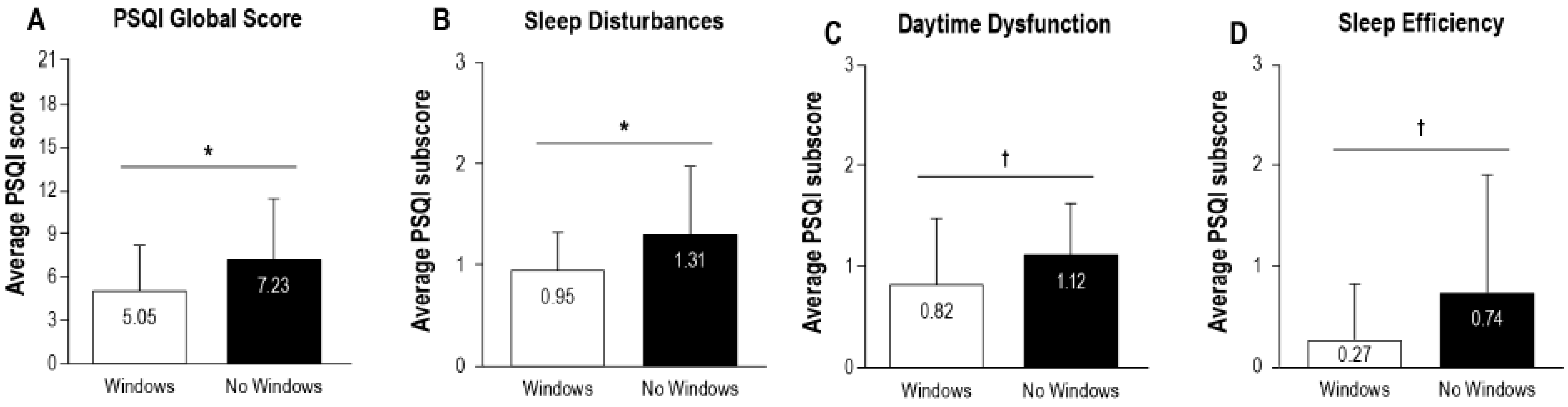

Figure 3—Pittsburgh Sleep Quality Index (PSQI) measures between workers in workplaces with windows (N = 22) and without windows (N = 27).

Cutter Suction Dredge (CSD)

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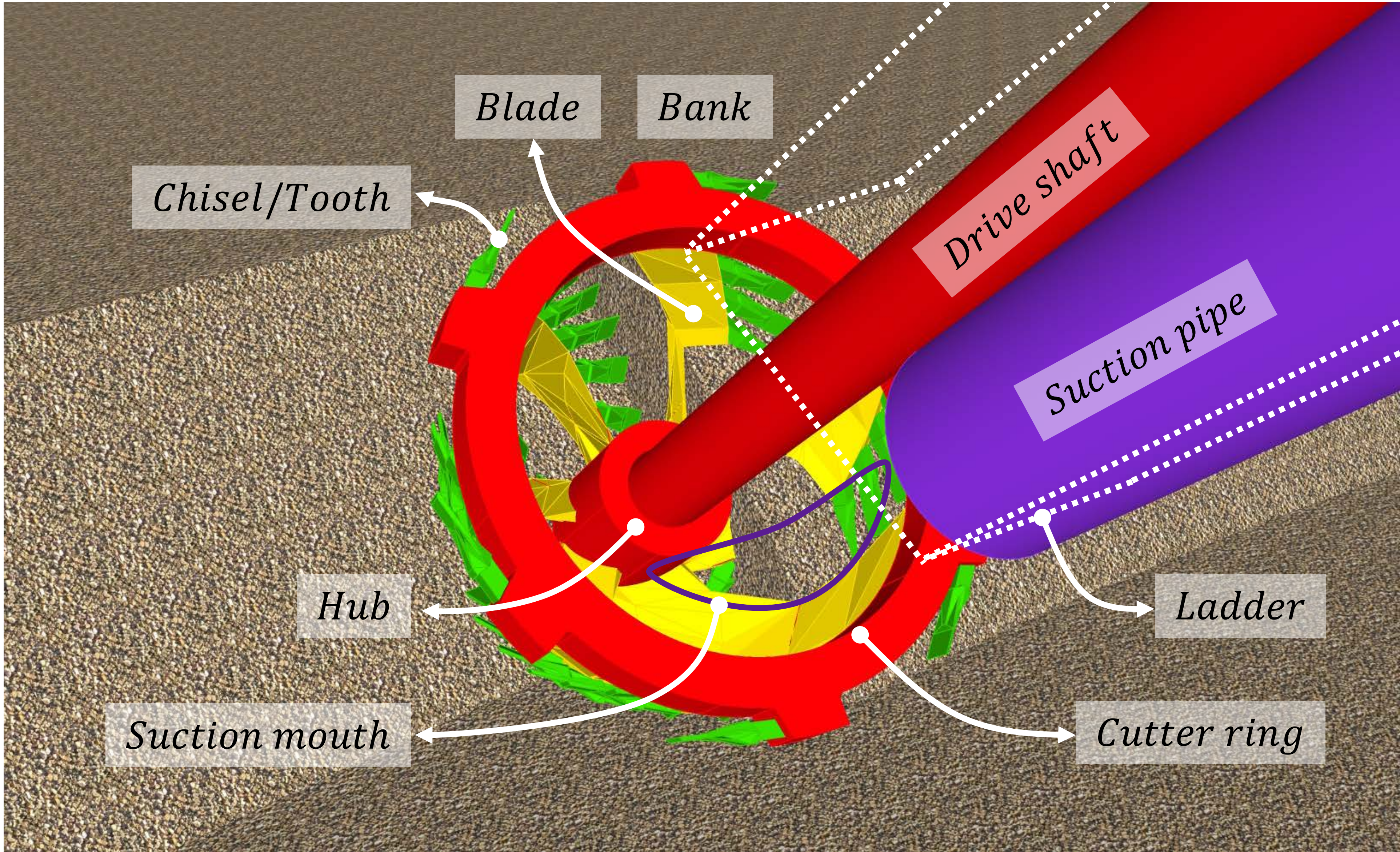
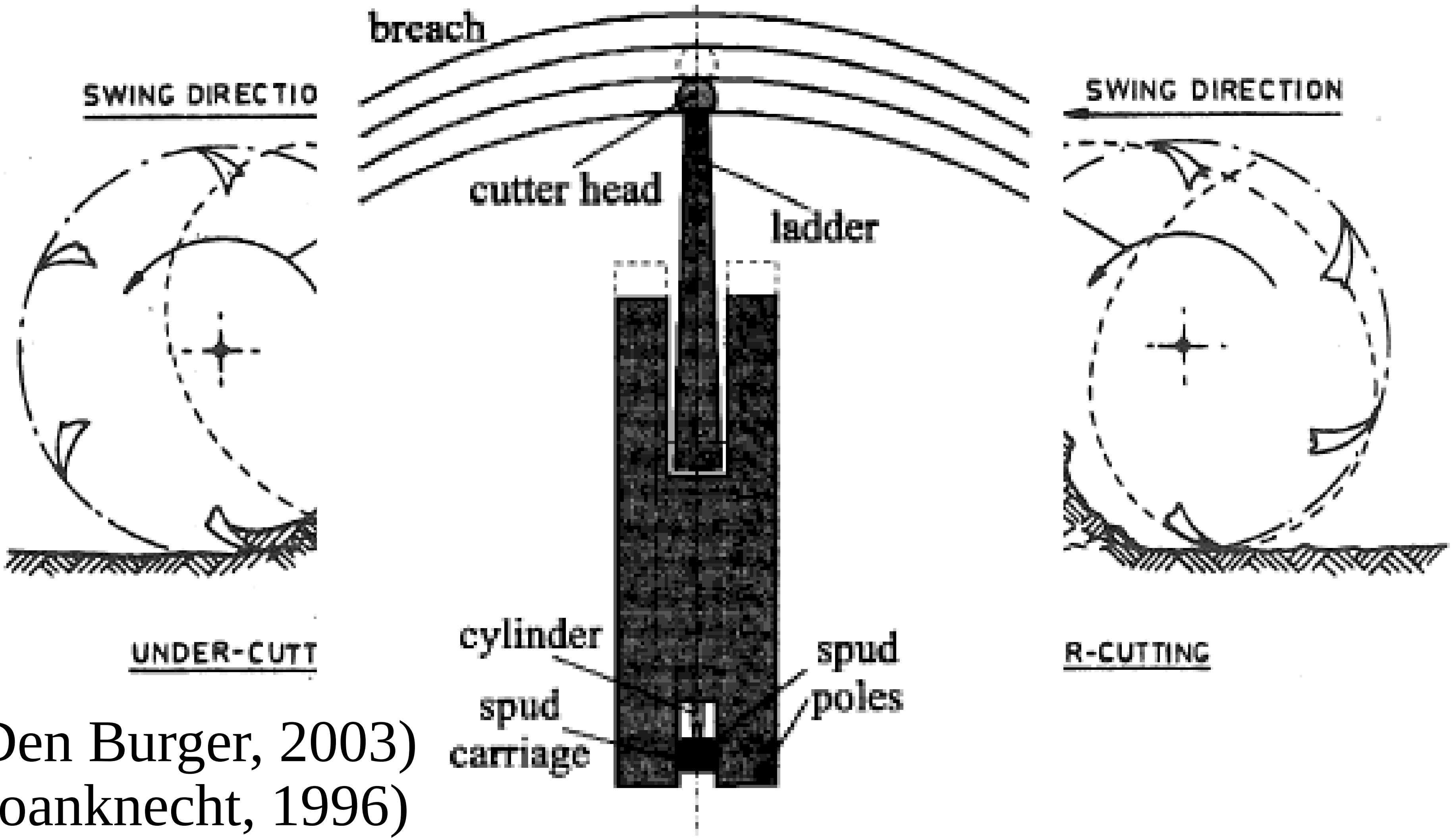


Cutter Suction Dredge (CSD)



(Den Burger, 2003)
(Joanknecht, 1996)

Regression Analyses

- Dimensionless numbers
  Joanknecht (1978), Slotta (1978), Hayes (1986), Andrassy et al. (1988), Hayes et al. (1988), Collins (1995), Hayes et al. (2000), Hayes et al. (2000)

  “[could] not explain suspended sediment variations very well “

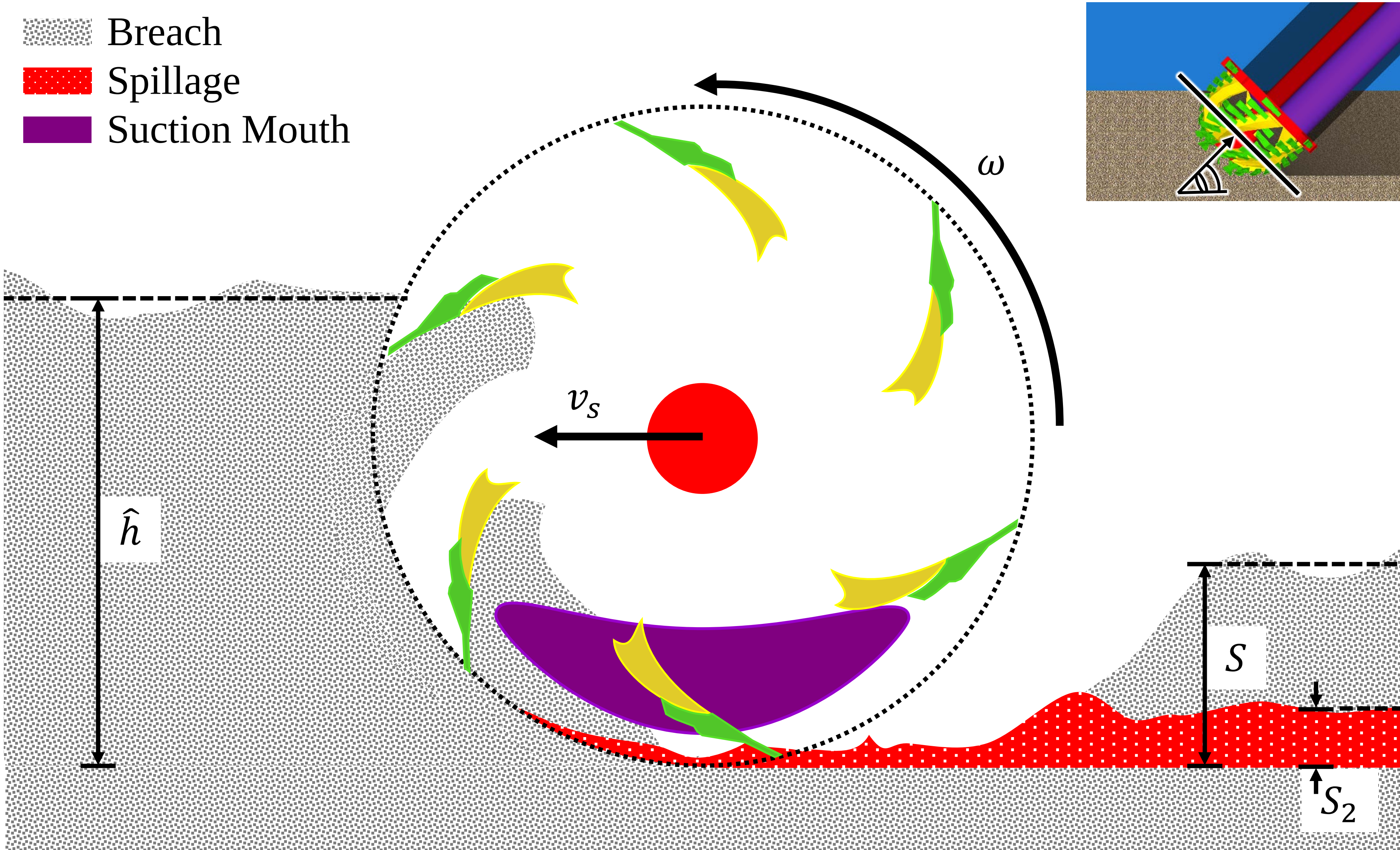
  “too limited range of operating parameters”

- $m_{eq} = \sigma_{eq}\rho_d V_{situ} f_{<63\mu m}$
  Becker et al. (2014)

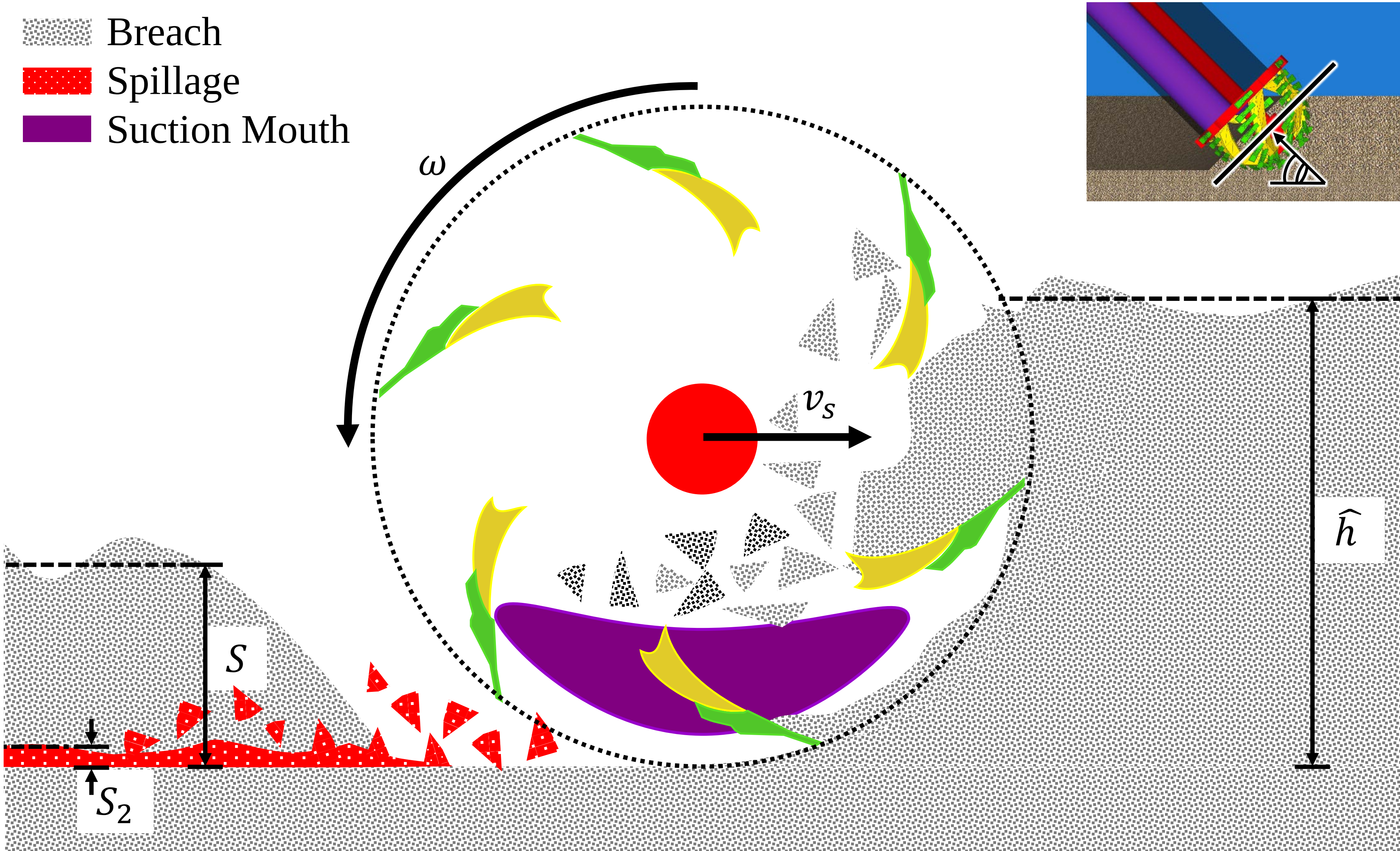
Spillage

"any soil that may be dislodged above the lowest cutter tip trajectory, but is not sucked into the suction pipe"

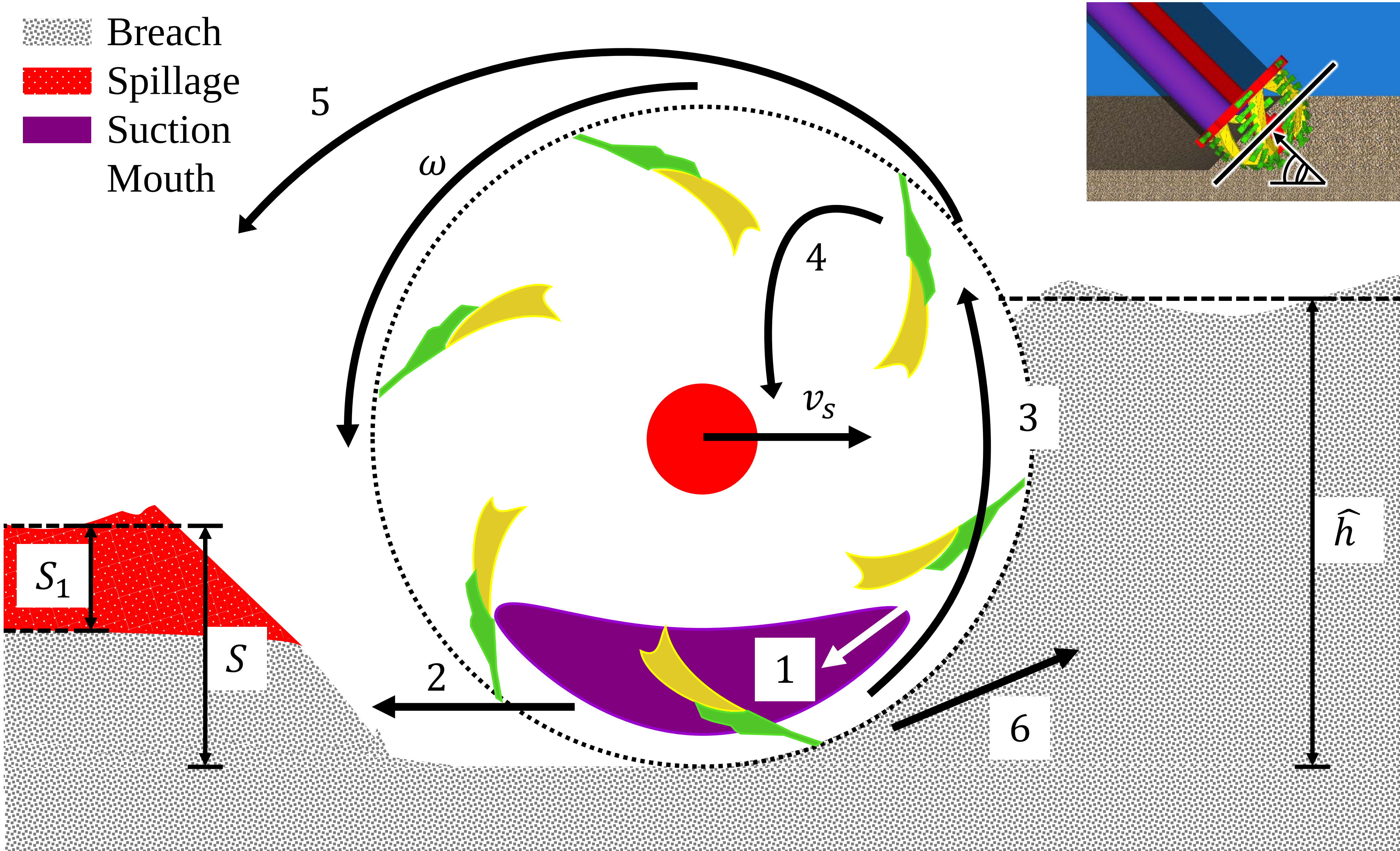
Rapid Redeposition (Over-cut)



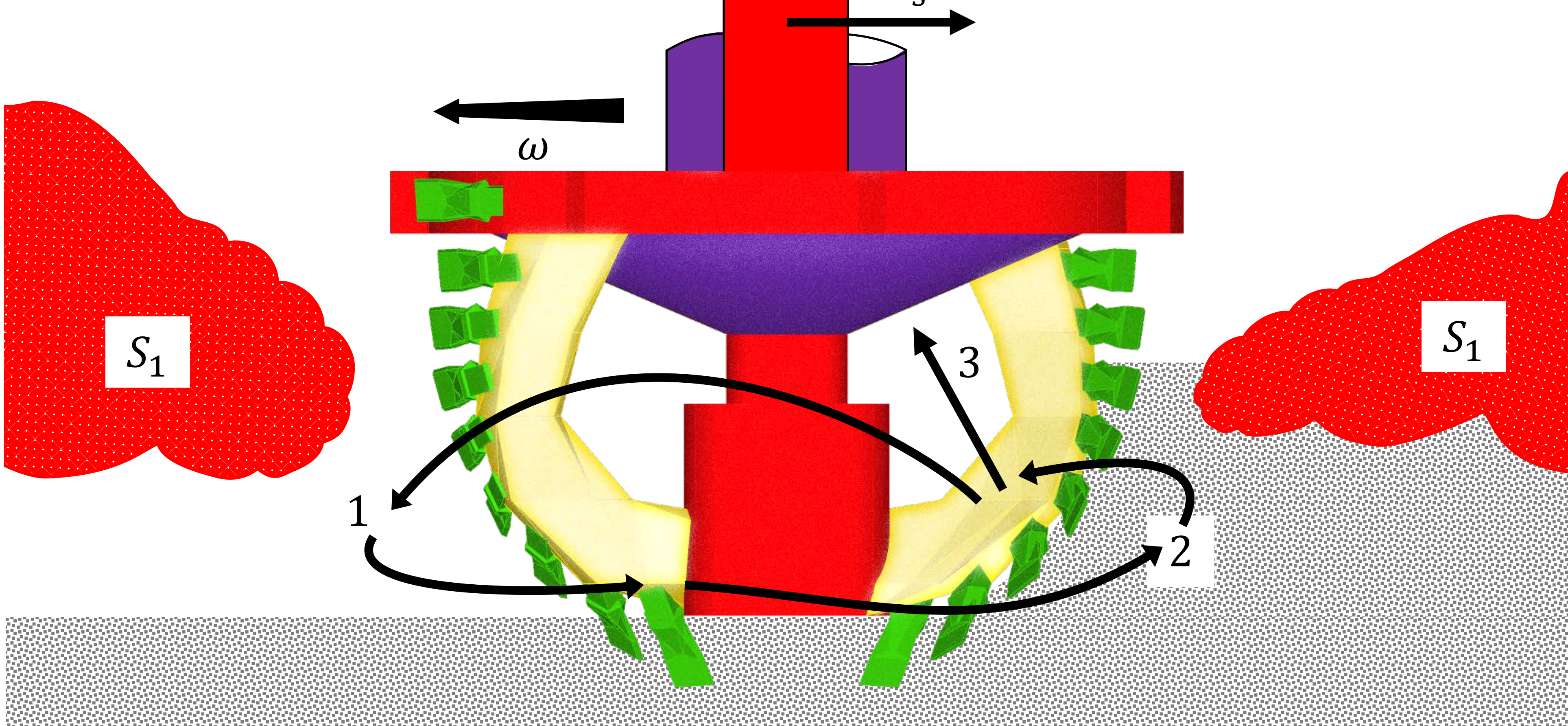
Rapid Redeposition (Under-cut)

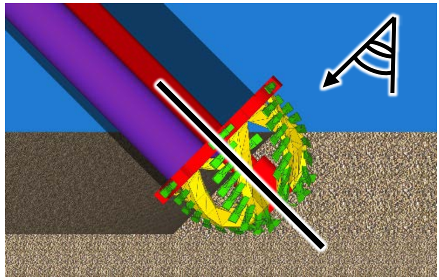


Centrifugal Advection (Under-cut)



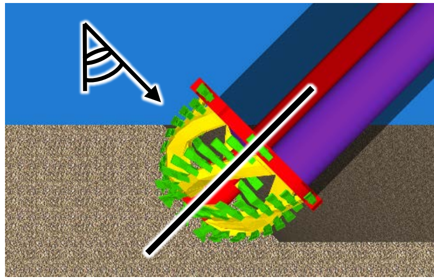
Centrifugal Advection (Under-cut)

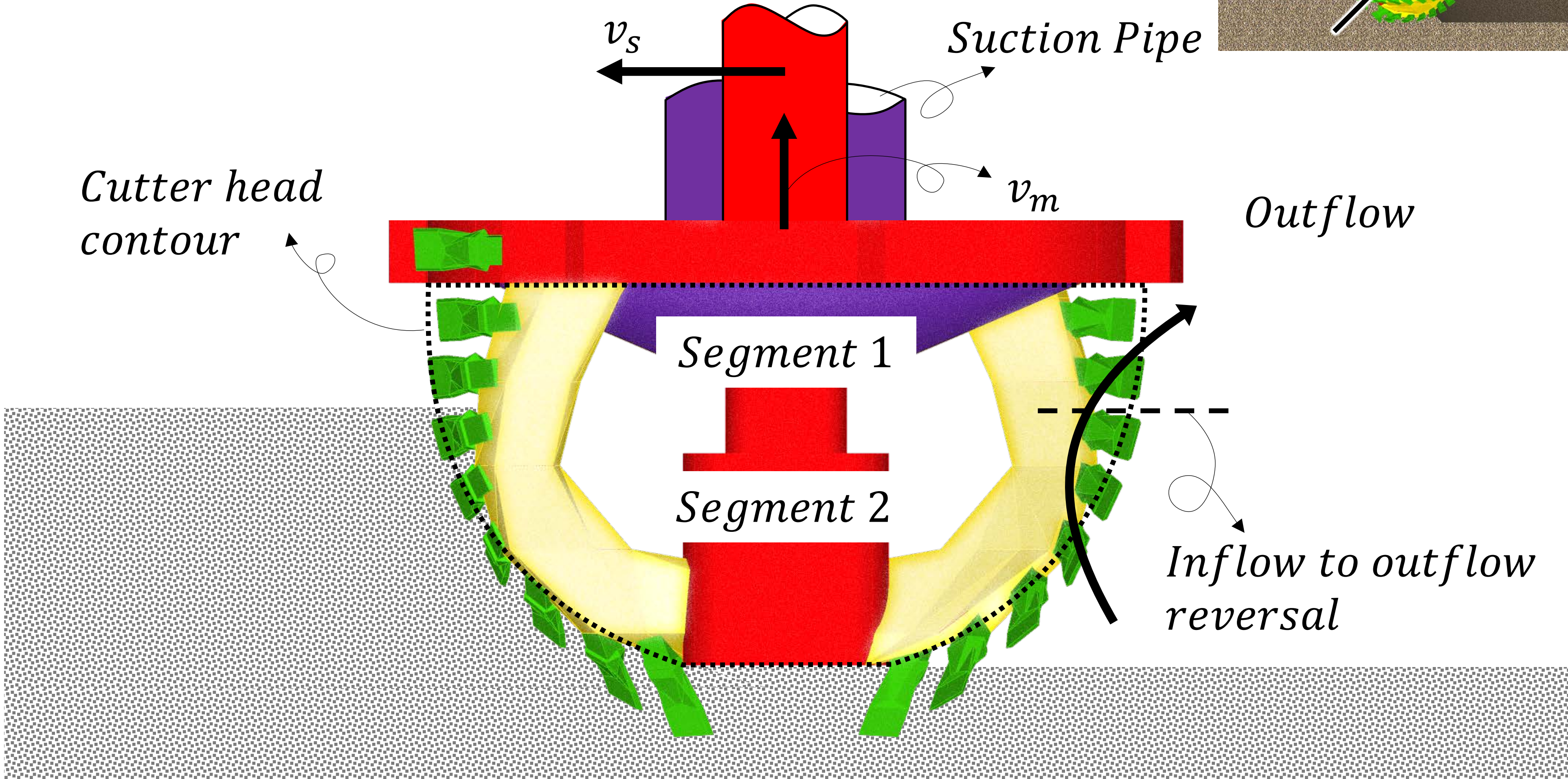




Zooming In On Centrifugal Advection

Breach
Observed Cutter Flow





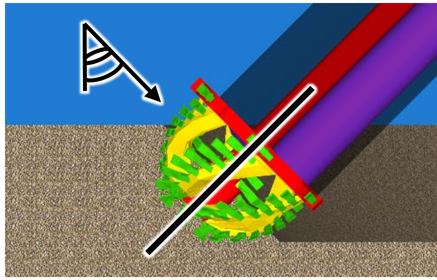
Experimental Findings

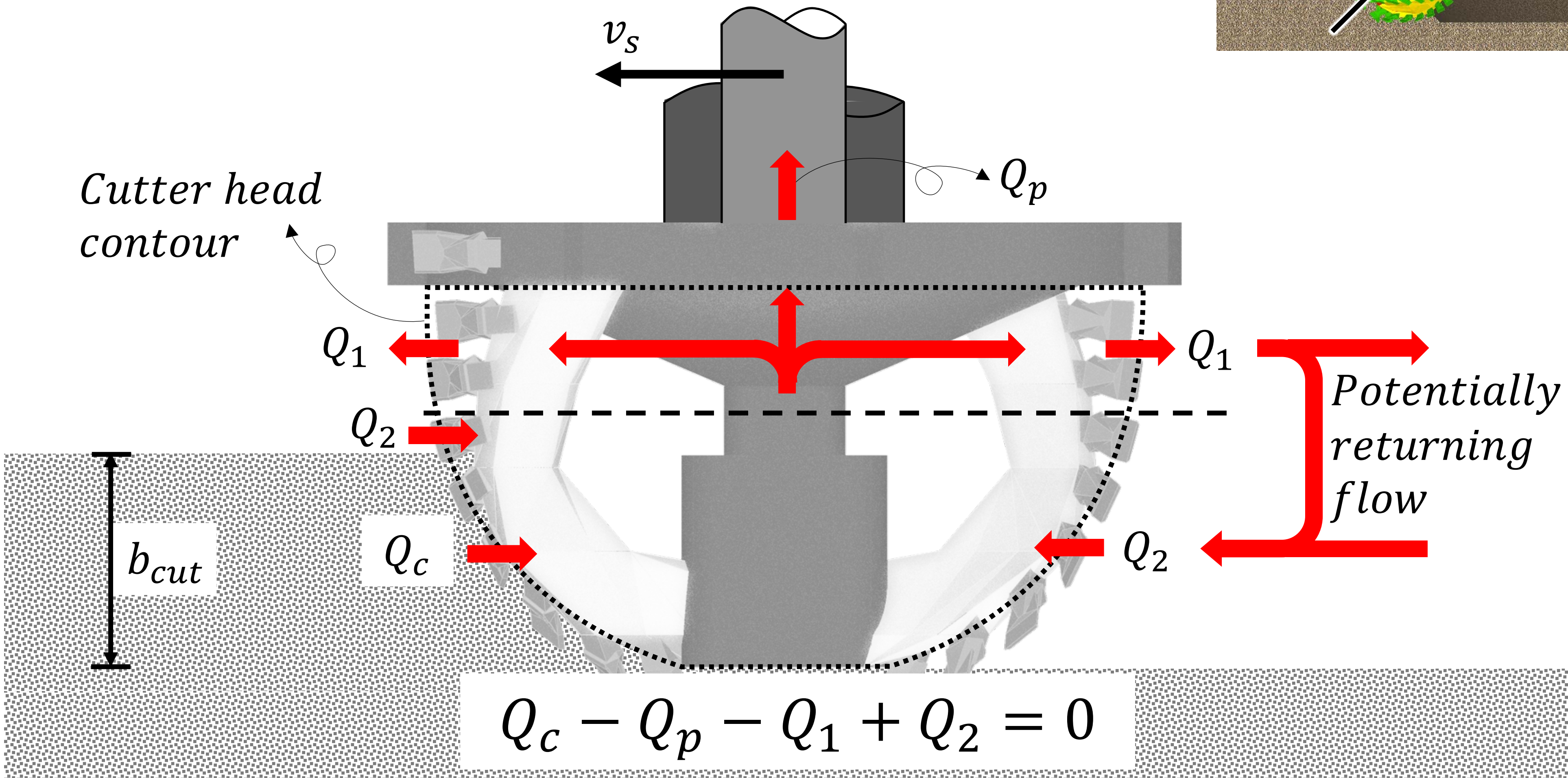
- For every mixture velocity there is a rotational velocity at which outflow starts

- The ratio was **constant**

- The ratio was nearly **identical** for under-cut and over-cut scenarios

Volumetric Flow Rate Balance





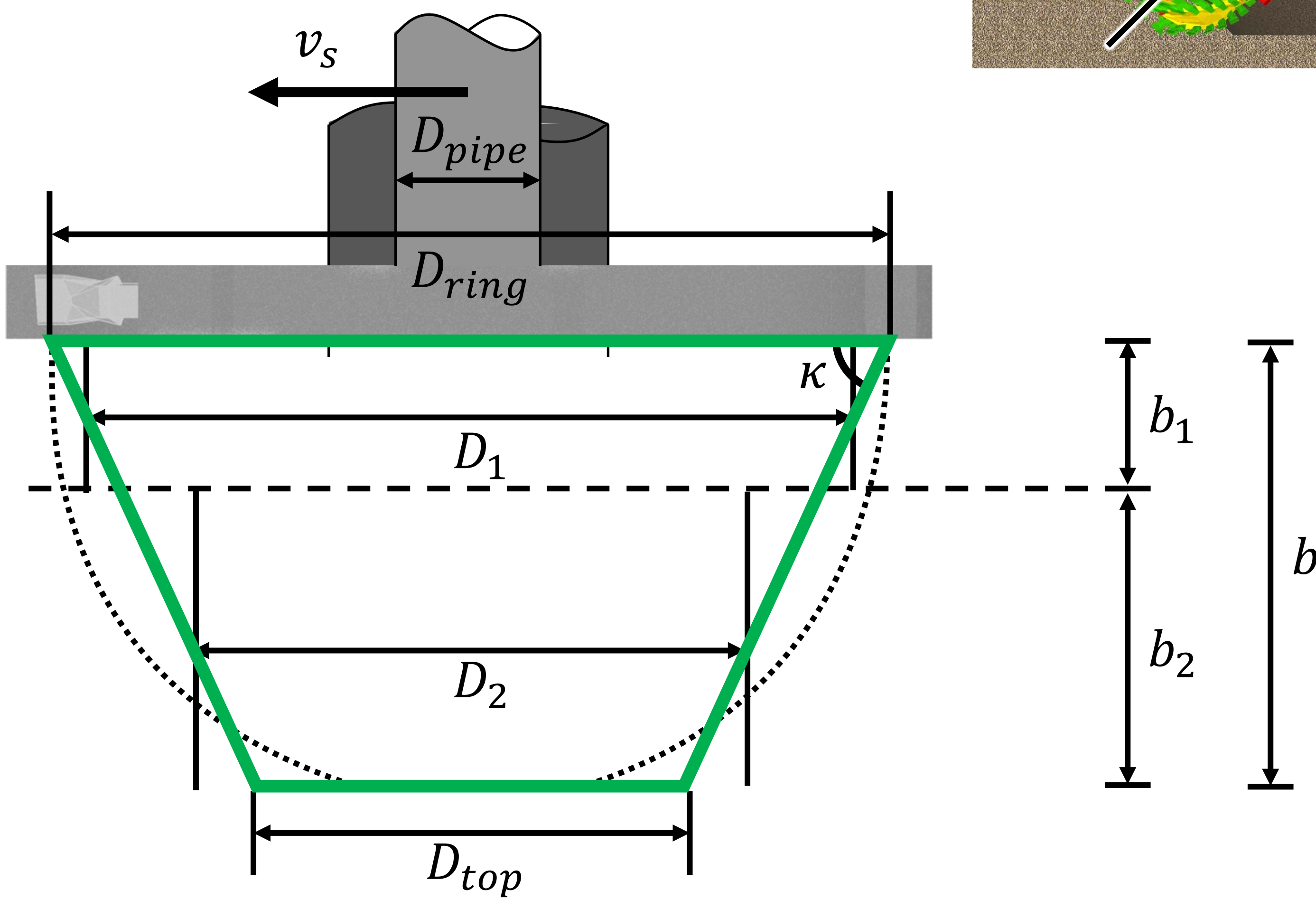
$$Q_c - Q_p - Q_1 + Q_2 = 0$$

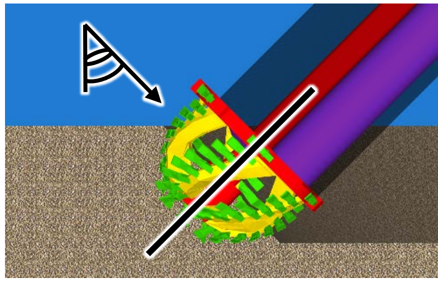
Assumptions

- Centrifugal and axial pump effect
  Miltenburg (1983), Den Burger (2003), Nieuwboer et al. (2017)
- Two segments
- Virtual radial discharge impeller, dynamically similar
- Uniform density in and around cutterhead
- Flow equilibrium
- No hydraulic transport through bank

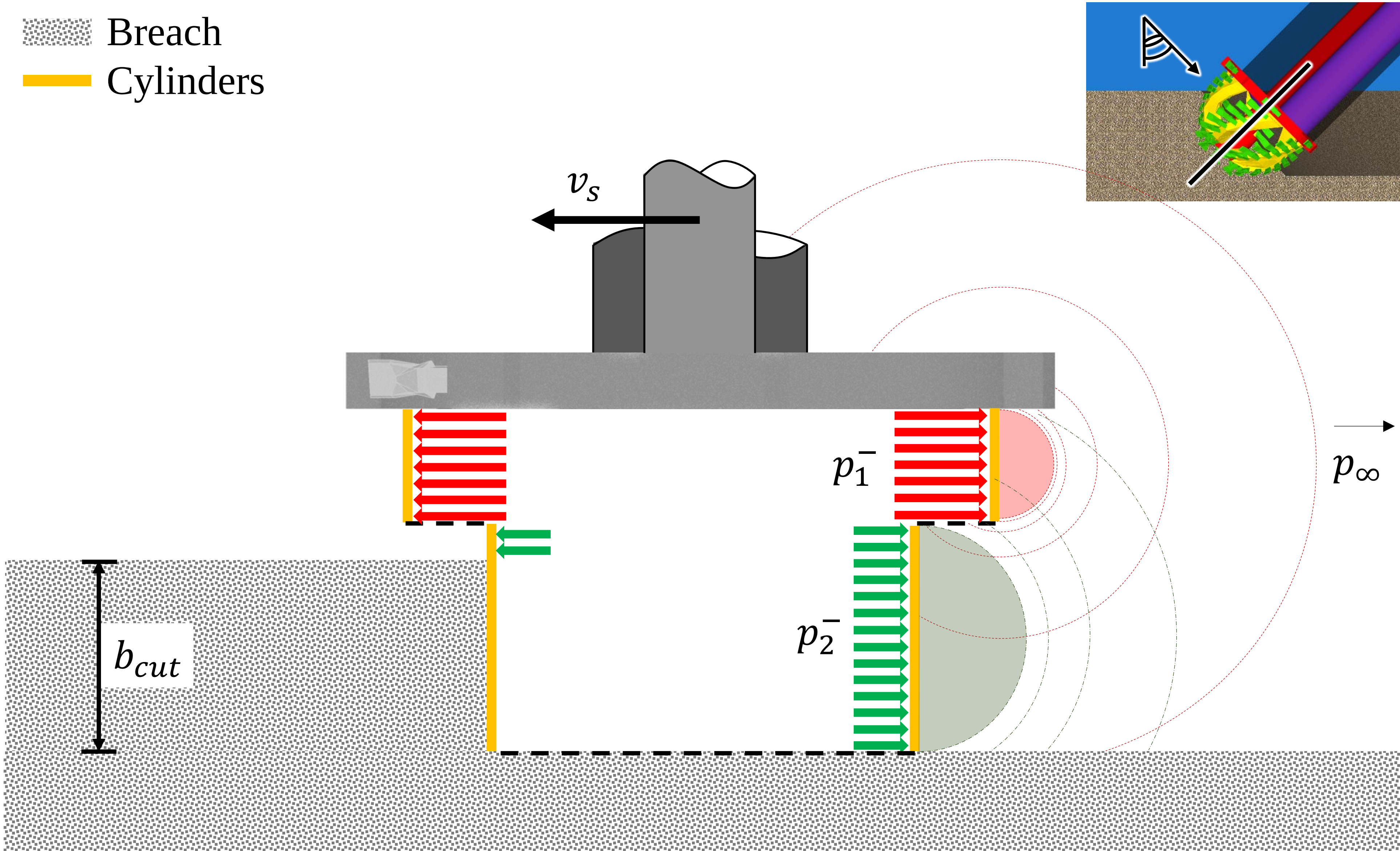
Geometry

Breach
Truncated cone

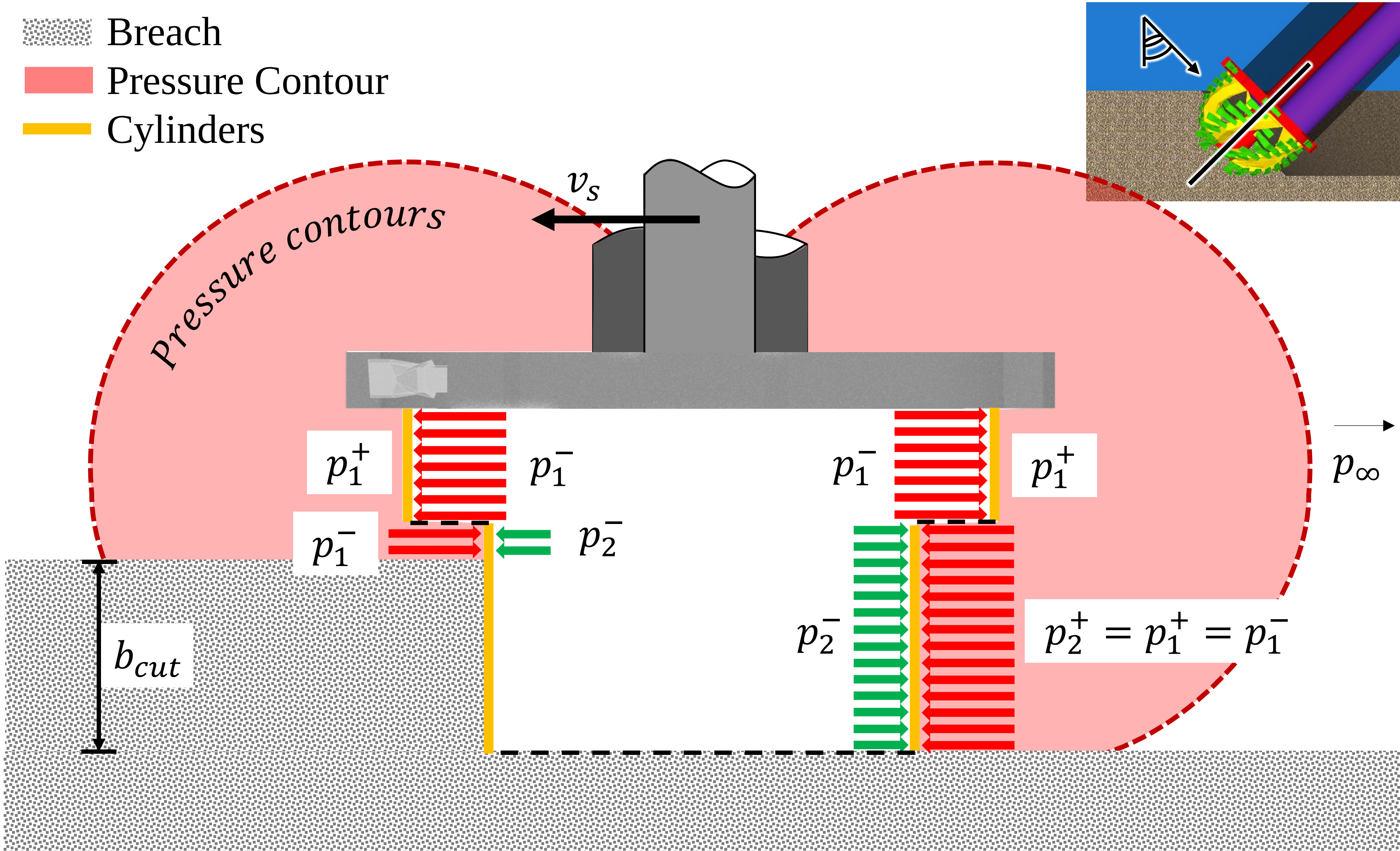




Pressure Assumption (1)



Pressure Assumption (2)



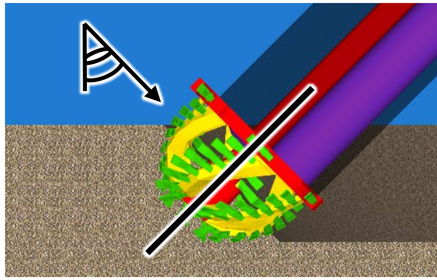
How to determine Q_1 and Q_2?

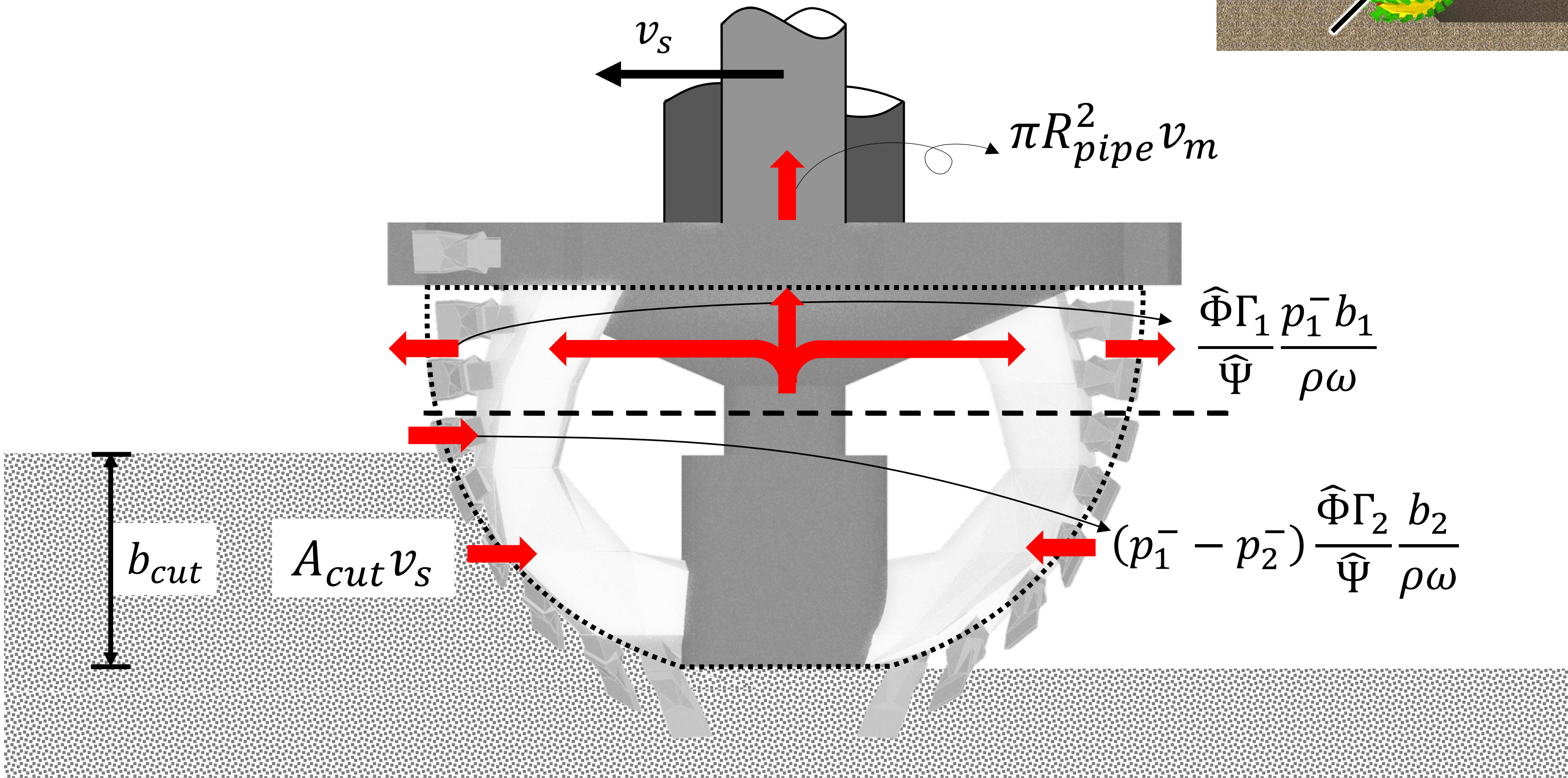
$$Q \propto \hat{\mathbf{\Phi}} b \omega D^2$$

$$p \propto \rho \omega^2 D^2$$

Volumetric Flow Balance

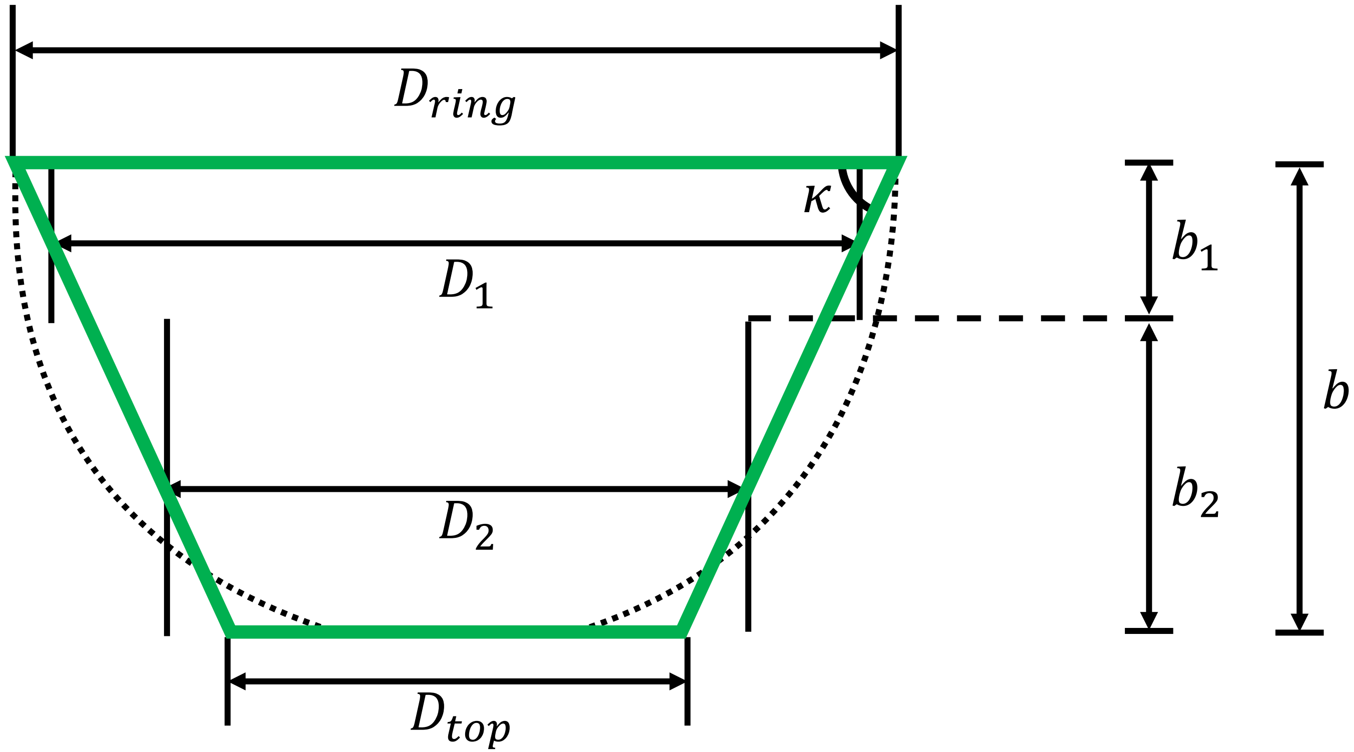
Breach
Flow



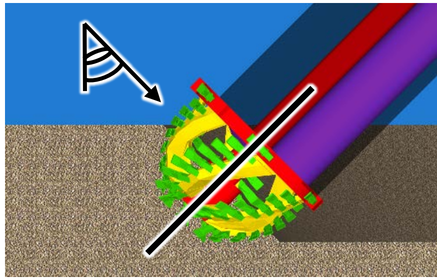


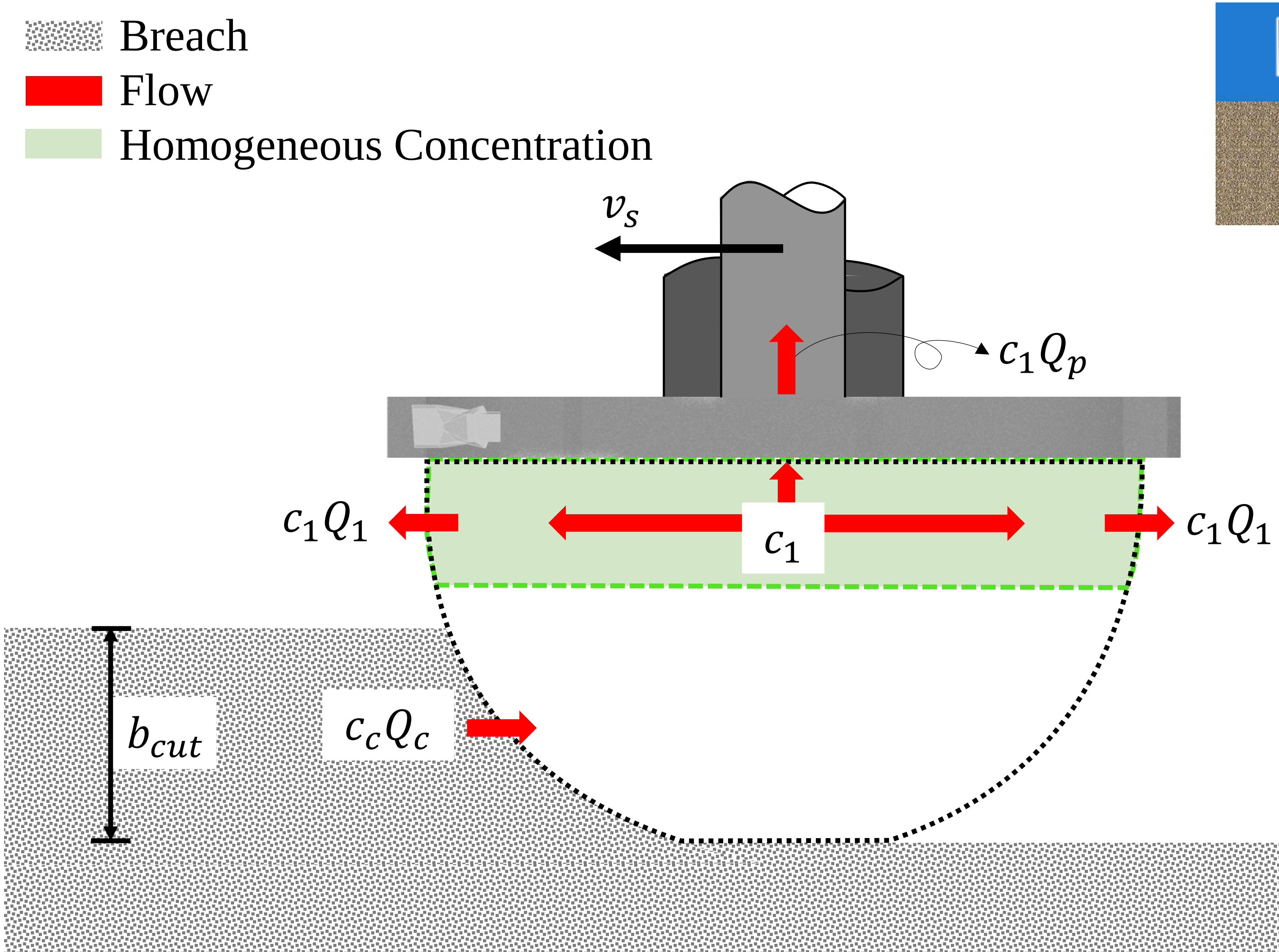
Iterative Problem

$$b_1 = \begin{cases} \dfrac{\widehat{\Phi}\Gamma_2(D_1^2 - D_2^2)b\omega + A_{cut}\boldsymbol{v_s} - \pi R_{pipe}^2\boldsymbol{v_m}}{\widehat{\Phi}(\Gamma_1+\Gamma_2)D_1^2\omega - \widehat{\Phi}\Gamma_2 D_2^2\omega}, & b_1 \geq 0 \\ 0, & b_1 < 0 \end{cases}$$



Ignore Density, Add Concentration





Adapted Flow Number

- Adaptation of Flow Number
  Nieuwboer et al. (2017)

$$\hat{\theta} = \theta^{-1} = \frac{\omega R_{ring}^3}{Q_p}$$

Results for Sand

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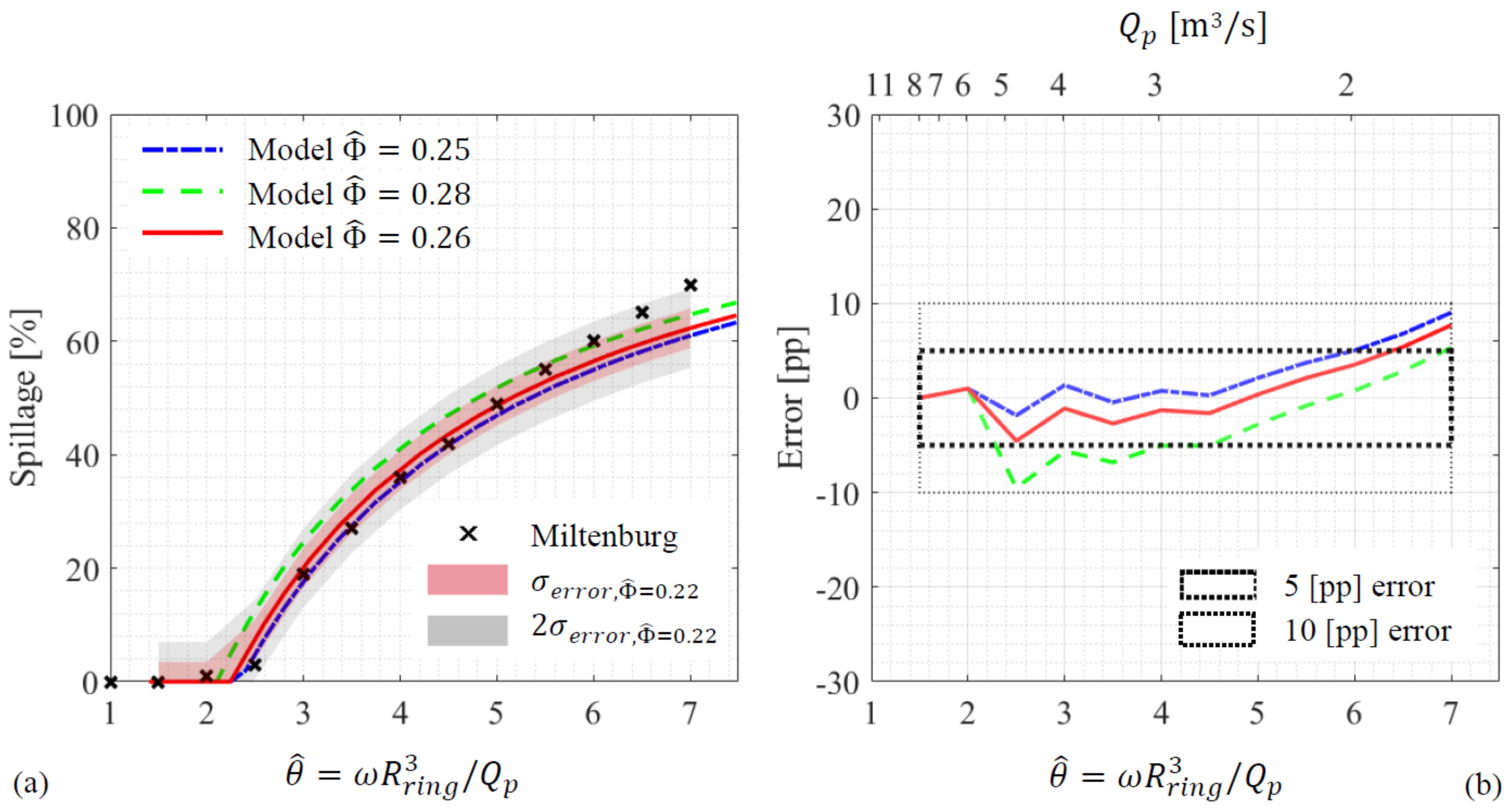
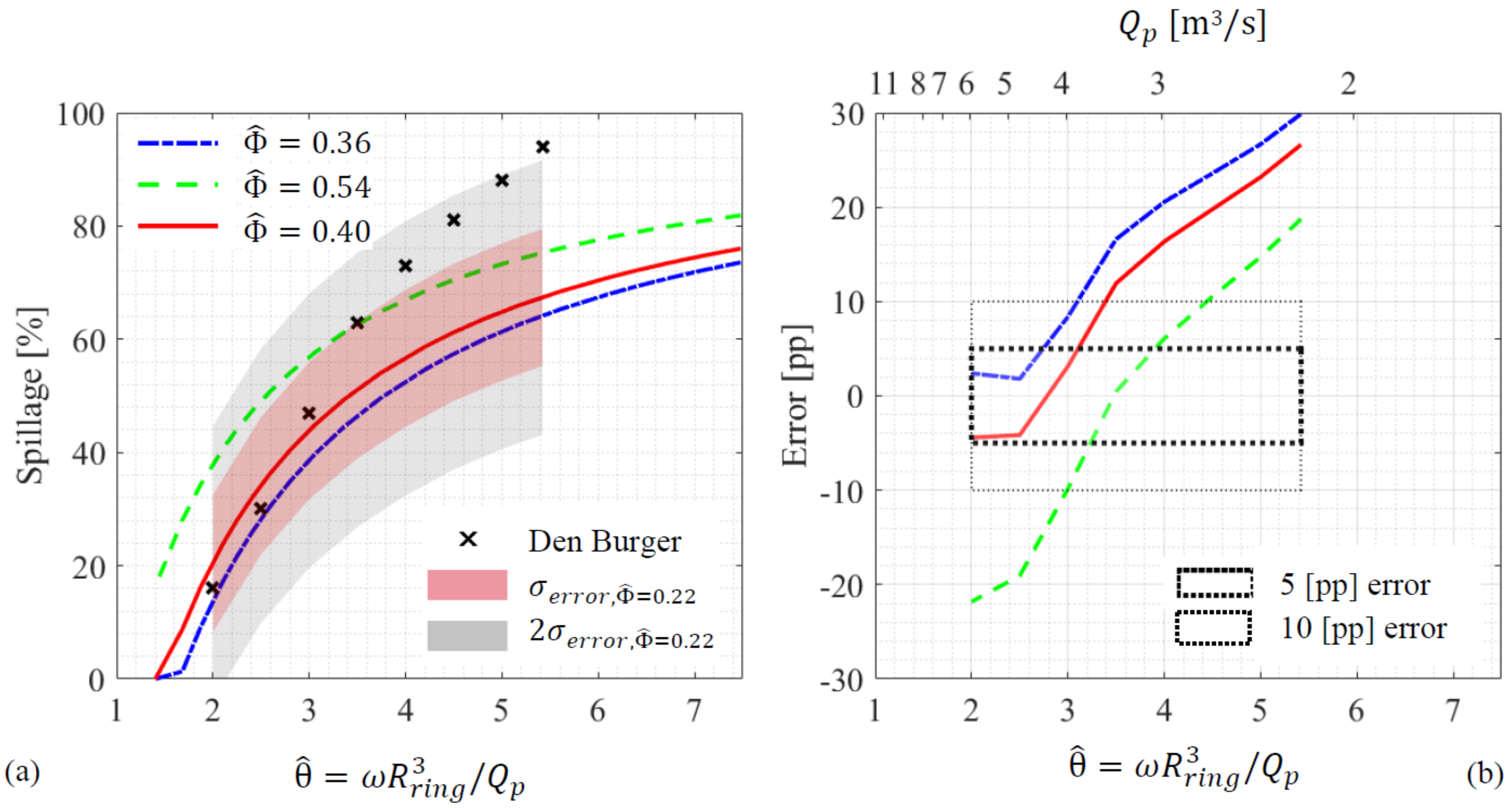


Spillage curve [%]

Error [Percentage Point]

Results for Rock



Spillage curve [%] Error [Percentage Point]

Discussion

- Sand spillage can be approximated reasonably
- Rock spillage is underestimated for low suction flow rates

Improvement

- Introduce density differences
- Add axial pump effect
- Examine pressure assumption
- Detailed cutter geometry
- Take into account other spillage sources for calibration


Thank you!