

Unearthing Mud's Hidden Strength – Micromechanics of the Yield Stress and Flow for Safer Dams and Disaster Prevention



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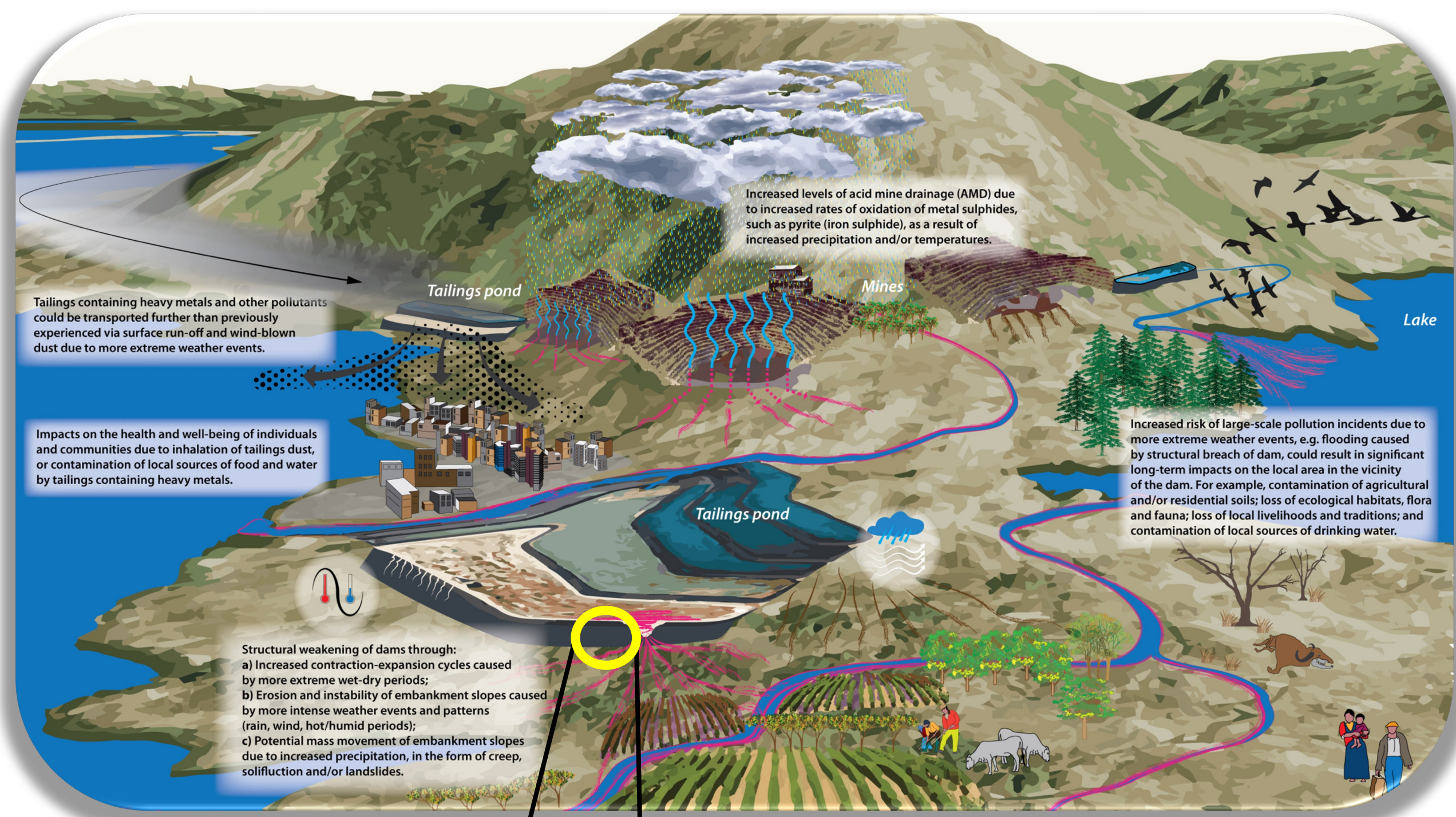
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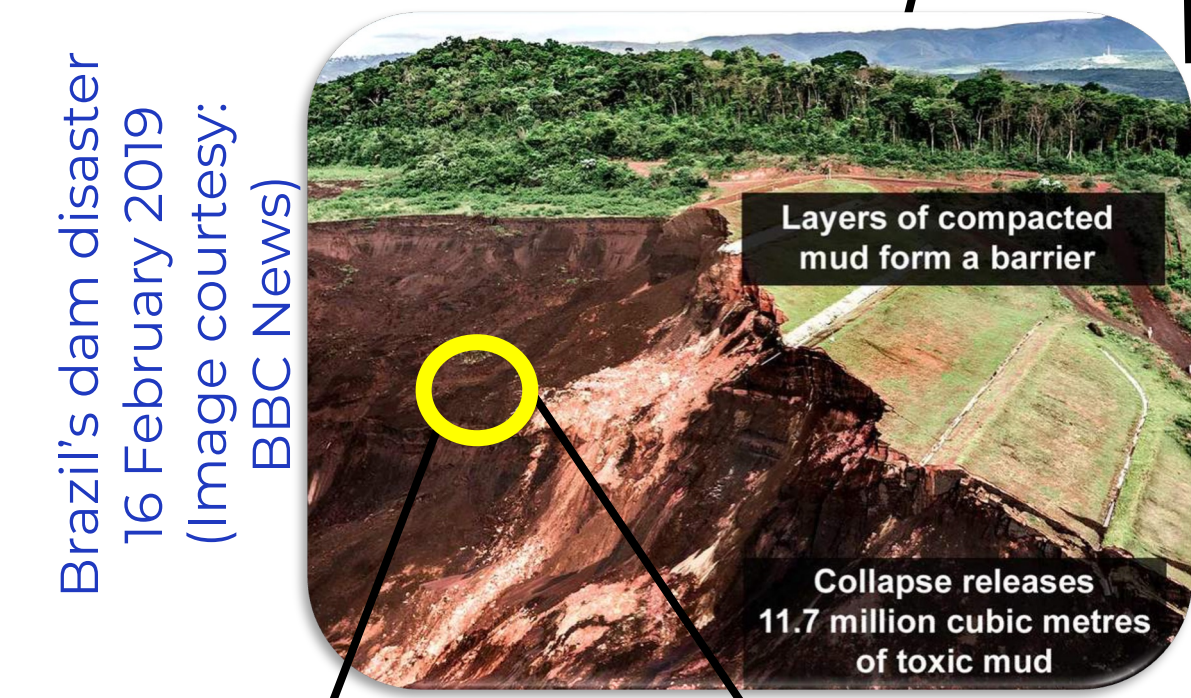
Motivation – The yield stress of mud determines the health of tailings dams



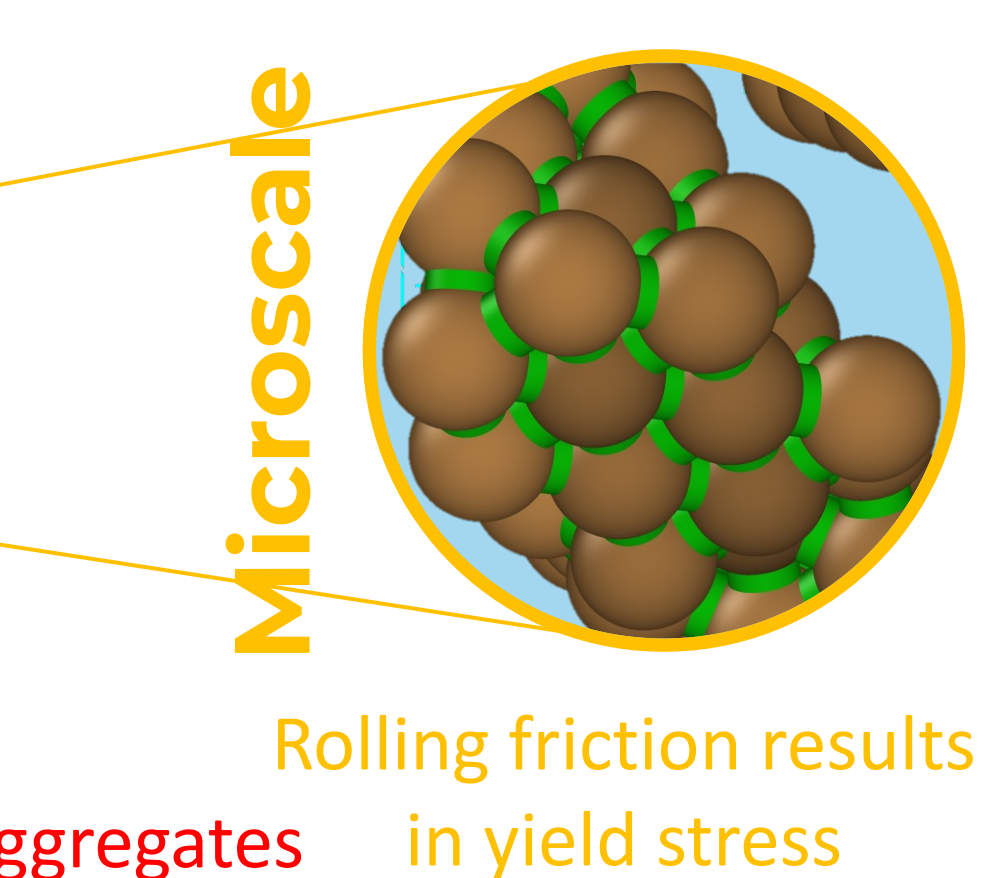
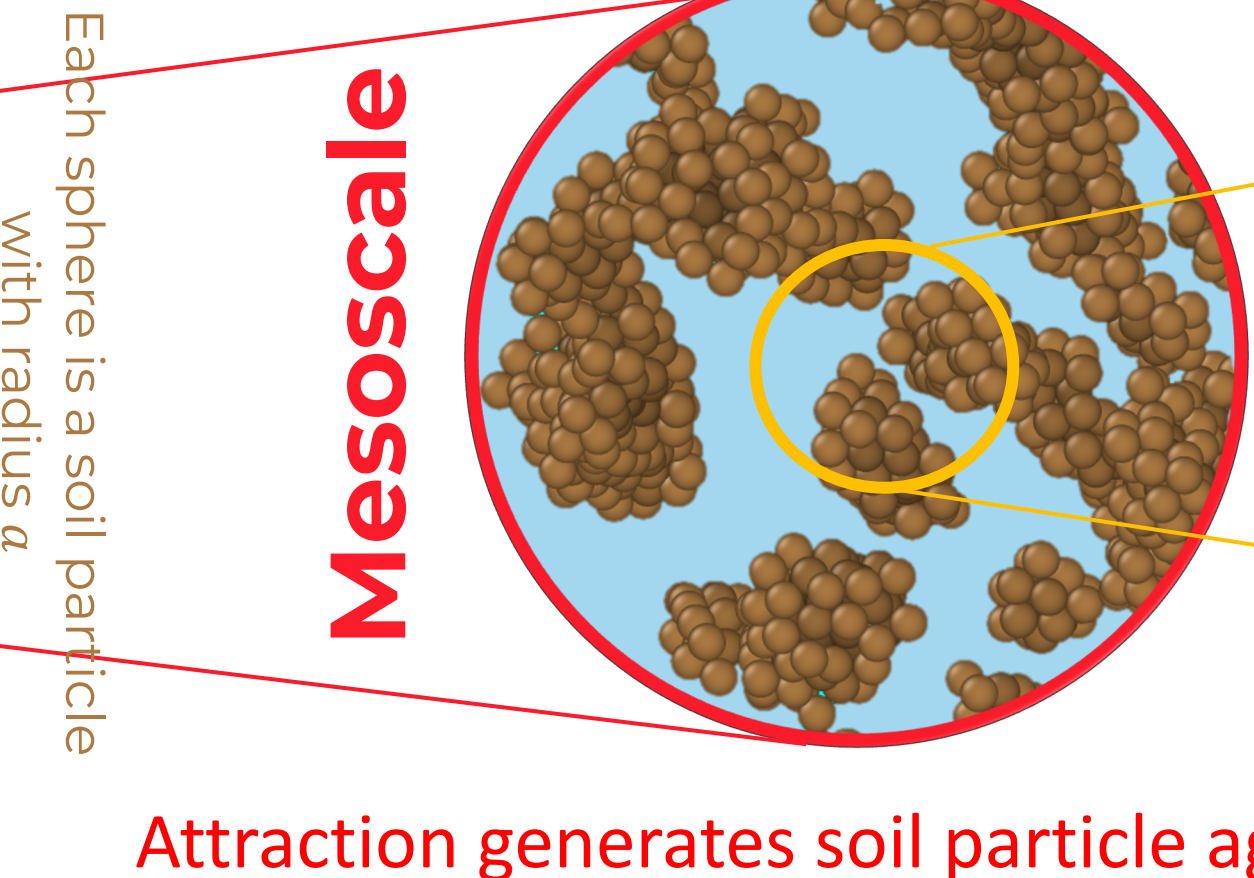
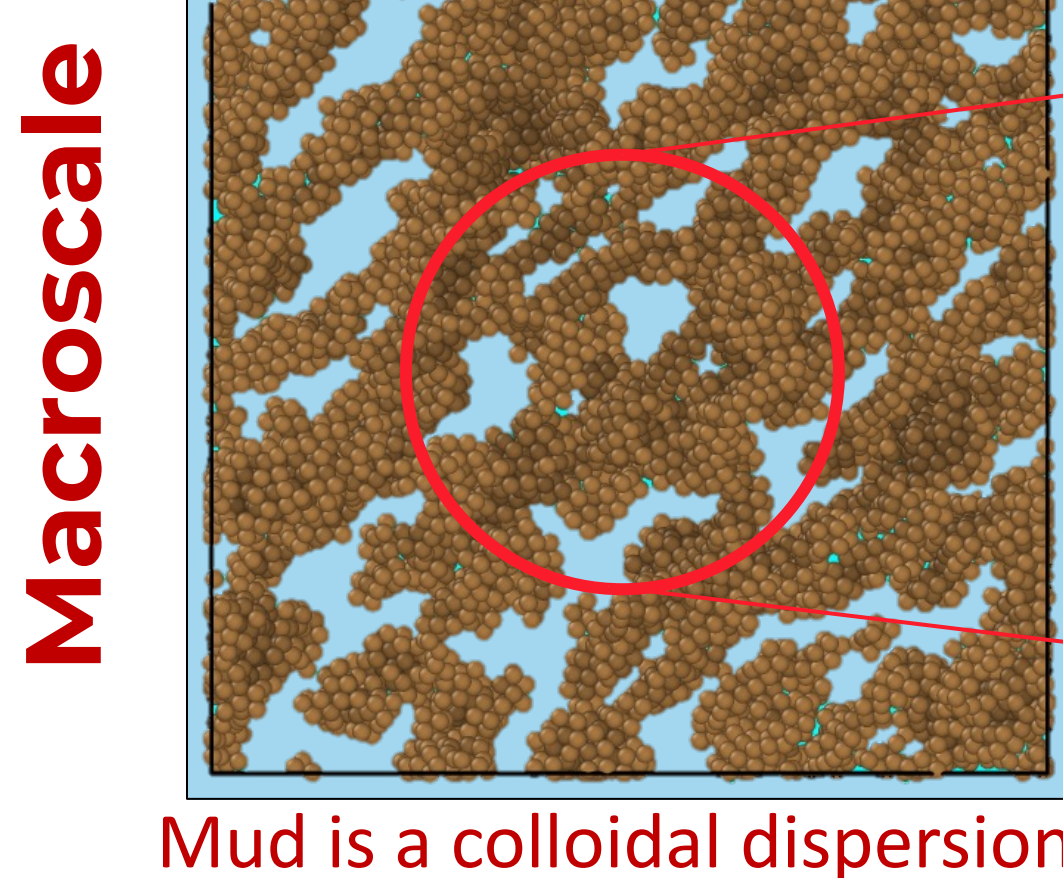
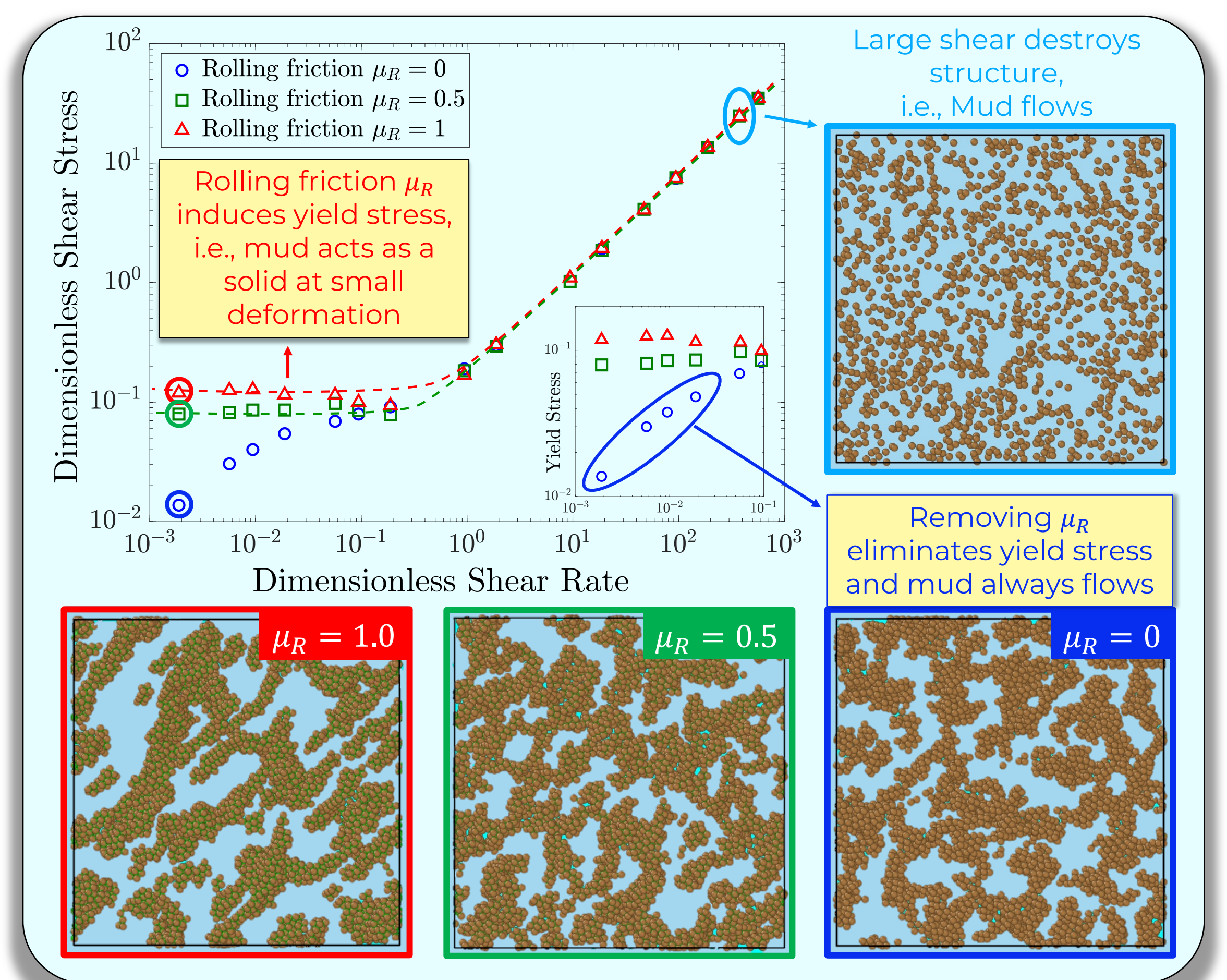
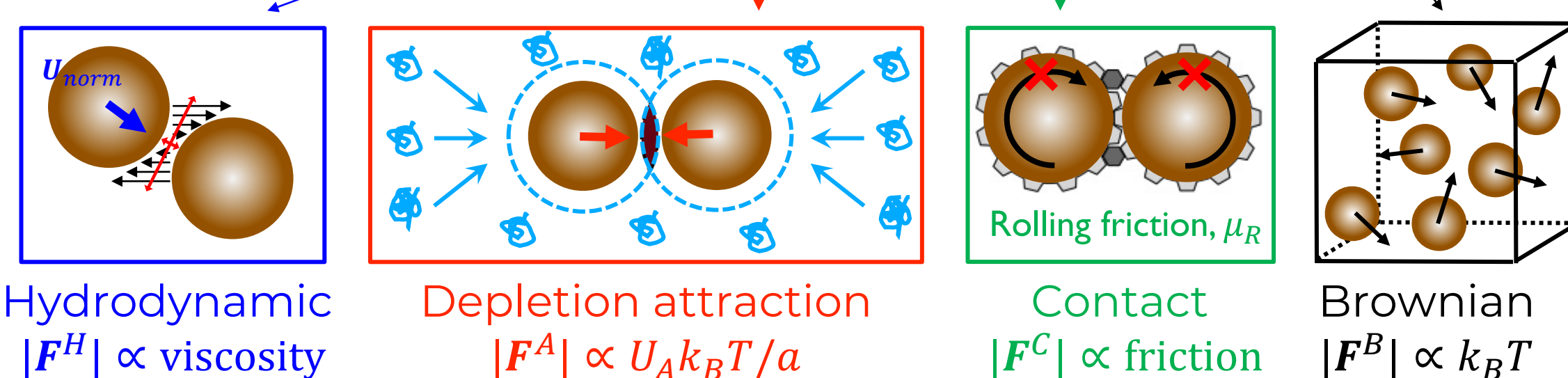
- Highly filled complex slurries are routinely encountered in Advanced Manufacturing, e.g., flow batteries, solar cell pastes, as well as in mud
- Specifically, 'mud' (a consolidated dense suspension) is used to construct tailings dams for storing byproducts of mining operations
- The presence of a *threshold yield stress* (i.e., the level of shear force a material can withstand before it starts to flow or yield) in mud supports its weight and keeps the dam functional
- However, a *delayed gravitational collapse* can lead to catastrophes like mudslides and dam-breaks with irrecoverable environmental and economic impacts, and loss of hundreds of lives [1]
- Hence, an understanding of the micromechanical origins of the yield stress in a complex slurry such as mud, and the transition to flow is crucial to predict & prevent such accidents
- 'Mud' is a highly filled complex slurry of weakly attractive irregular soil particles (nanometers – micrometers in size) in water, a.k.a. a colloid

[1] "Mudslides in Brazil kill at least 94 people," (16 February 2022). *The New York Times*; "Barragem de rejeitos da Vale se rompe e causa destruição em Brumadinho (MG)," [Vale's tailings dam collapses and causes destruction in Brumadinho, Minas Gerais], (25 January 2019). *Correio Braziliense* (in Brazilian Portuguese); "Dam burst at mining site devastates Brazilian town," (6 November 2015). *Al Jazeera English*. AFP and Reuters.

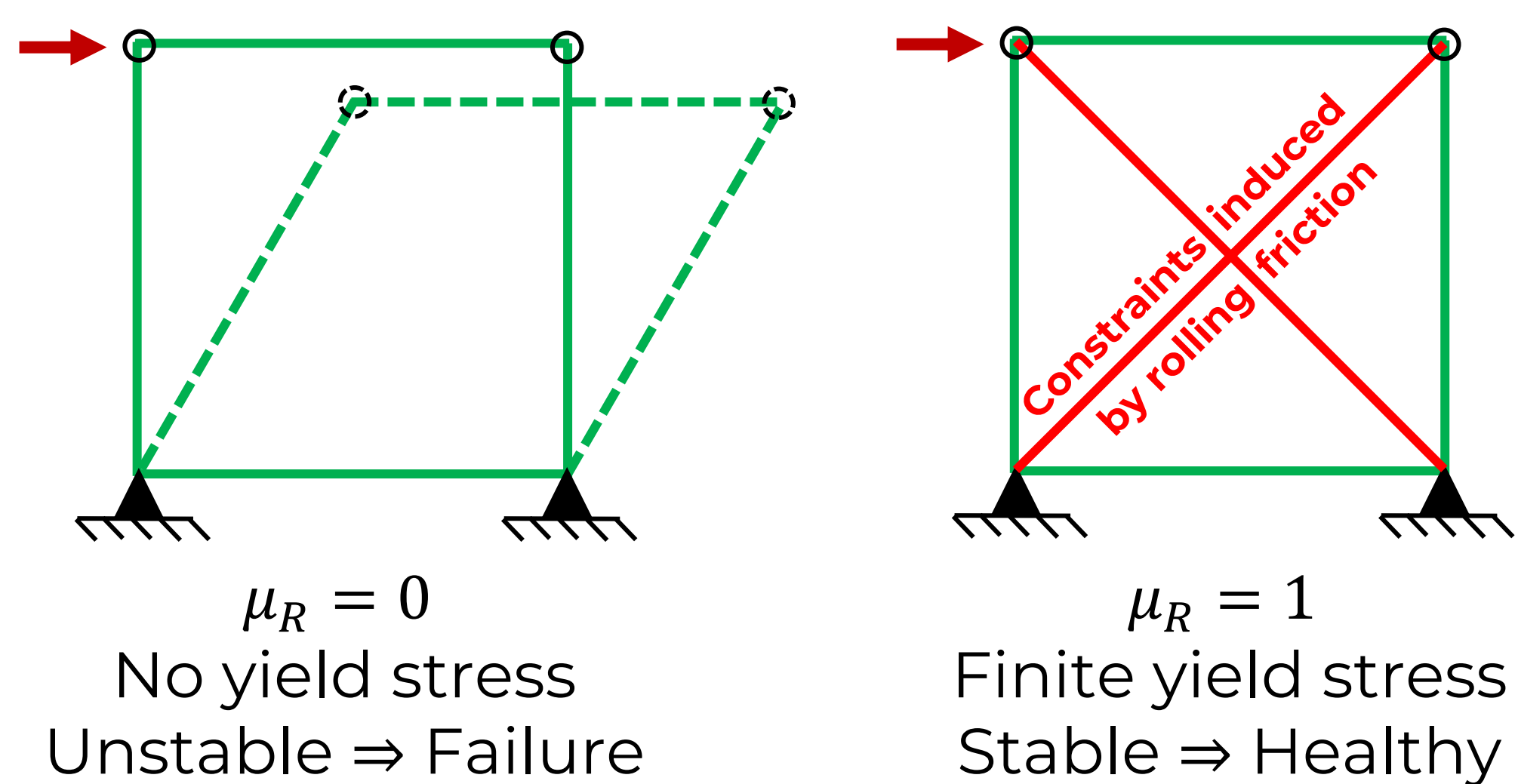
Methodology



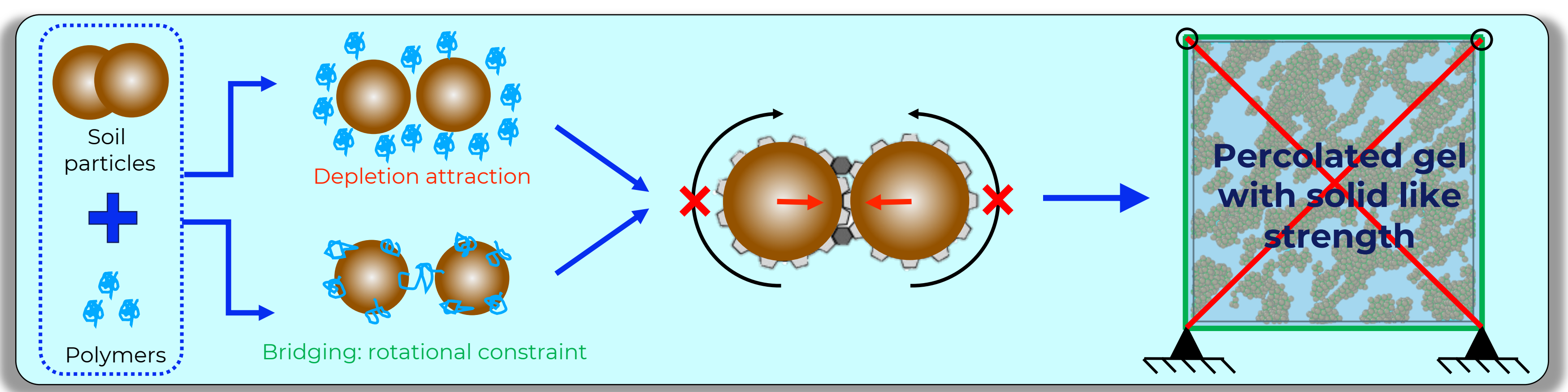
$$M \frac{dU}{dt} = \left(\begin{matrix} F_{hydro.} \\ T_{hydro.} \end{matrix} \right) + \left(\begin{matrix} F_{att.} \\ T_{att.} \end{matrix} \right) + \left(\begin{matrix} F_{cont.} \\ T_{cont.} \end{matrix} \right) + \left(\begin{matrix} F_{Brown.} \\ T_{Brown.} \end{matrix} \right)$$



Safeguarding tailings dams

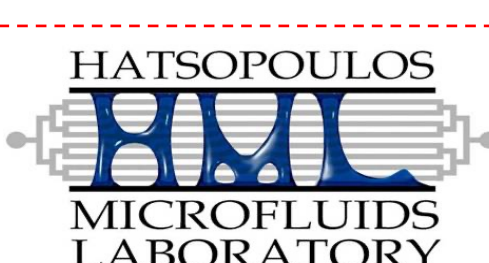


- Attraction between the particles and presence of constraints to their relative rotational motion together result in development of a yield stress [2, 3]
- Ways to incorporate both of these mechanisms simultaneously in mud slurries can improve the health of tailings dams; avoiding rolling constraints in flow battery slurries can help it flow easily and improve performance
- Attraction can be induced by adding dilute amounts of polymers, which give rise to attractive *depletion interactions* [4]
- By modifying the surface chemistry of particles, e.g., H-bonding or bridging interactions, can result in rotational constraints akin to rolling friction [5]



[2] More, R.V., & McKinley G.H., International Congress on Rheology 2023. [3] Liddel, P. V., & Boger, D. V., *JNNFM*, 63.2-3, 235-261, 1996. [4] Asakura S. & Oosawa, F. J., *Polym. Sci.*, 33, 183-192, 1958. [5] James, N.M., et al., *Nat. Mater.*, 17, 965-970, 2018.

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under the Seed Project: Data-Driven Discovery of Complex Material Responses for Digital Manufacturing | Digital Transformation in Manufacturing (with connections to soil erosion/transport for Sustainable Cities and Earth Systems)