Across-Scale Geomechanical Evaluation of Rain Intensity, Slope and Sand Type on Post-Wildfire Mudflow Composition and Onset Mechanisms

Ingrid Tomac[1], Jonathon Chavez de Rosas[1], Melissa Lepe[2], Wenpei Ma[1], and Mahta Movasat[1]

[1]University of California San Diego
[2]University of California Irvine

November 22, 2022

Abstract

Post-wildfire mudflows have intensified in recent years due to extreme wildfire occurrence, causing significant damage and infrastructure threats. However, despite recent advancements, across-scale geotechnical characterization of mudflow onset and flow behavior remains a challenge. We present a novel experimental and theoretical understanding of the sand type and rain intensity roles on mudflow onset and composition, integrating micromechanics and laboratory experiments. The analysis shows that hydrophobic fine sand, a consequence of wildfires, significantly enhances raindrops' downhill velocity and splash due to Cassie-Baxter-type surface, as opposed to medium or coarse sand, which affects raindrops as Wenzel surface wettability model. We use micromechanical and single-drop interactions with sand particles to explain erosion on the intermediate scale laboratory tests. Raining experiments on hydrophobic sloped flumes evaluate different slope failure mechanisms in fine, medium, and coarse hydrophobic sand as erosion patterns and seepage induced infinite slope failure in the case of embedded hydrophobic layers. The sand type also affects the spatio-temporal dynamic of erosion onset and distribution of eroded material and overflown rainwater. Surprisingly, we detected a possible equilibrium state where the eroded surface roughness changes affect water overflow and lead to an equilibrium state with very little subsequent erosion under constant rain intensity. On the other hand, erosion gradually increases after the rain starts, reaches a peak, and then subsides very quickly in coarse sand. In contrast, fine sand erosion continues for a longer time but decreases as the surface roughness increases. Furthermore, micromechanical investigation of mixtures of hydrophobic sands, water, and air gives an insight into air entrapment during flow and transport of mudflows. Hydrophobic sand particles attach to air bubbles and form agglomerates, contributing to the mixture heterogeneity and affecting flow and transport properties. Sand particle size, due to gravity, also plays a role in the amount and size of resulting agglomerates. Covering air bubbles with attached sand particles decreases the post-wildfire mudflow density up to 33% in laboratory conditions.

Across-Scale Geomechanical Evaluation of Rain Intensity, Slope and Sand Type on Post-Wildfire Mudflow Composition and Onset Mechanisms

Ingrid Tomac[1], Melissa Lepe[2], Wenpei Ma[3], Mahta Movasat[3] and Jonathon Chavez de Rosas[4]

Department of Structural Engineering

University of California, San Diego

[1]Assistant Professor

[2]Undergraduate student (UCSD STARS)

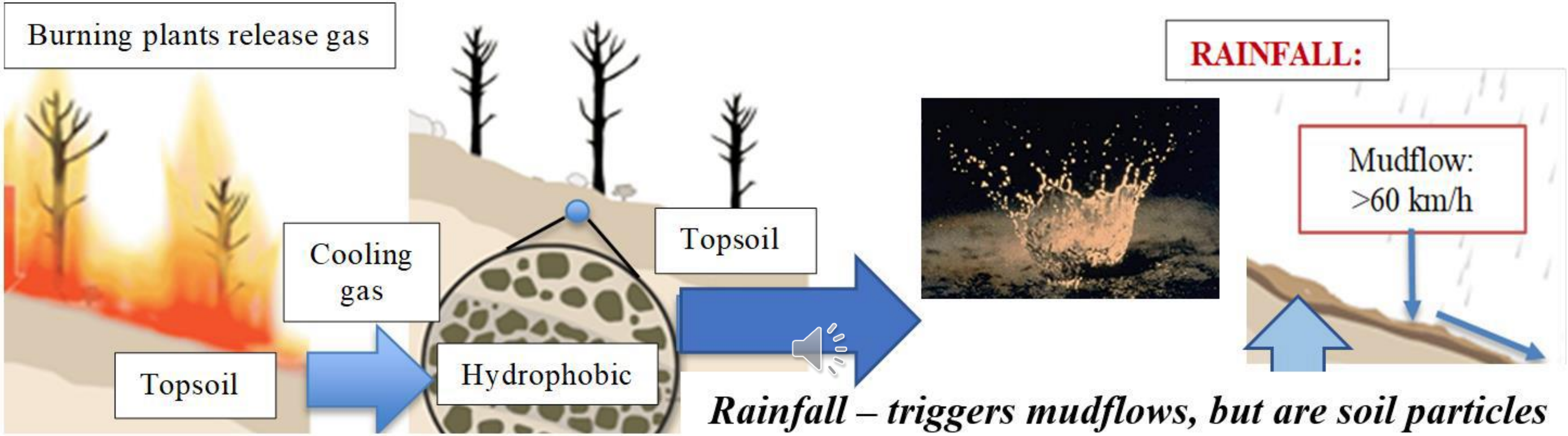
[3]Ph.D. Student

[4]M.S. Student

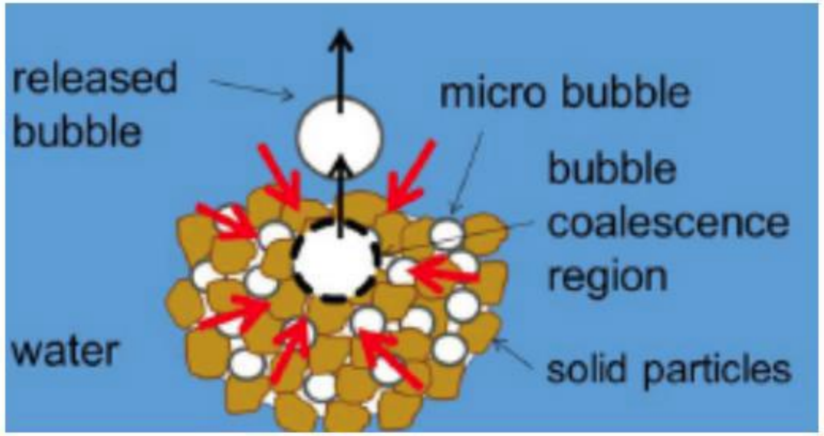
Presentation Outline

1. Background and motivation
2. Materials and Methods
3. Single raindrop experiments on different sands
4. Flume raining experiments
5. Mudflow composition
6. Air capturing inside of the mudflow
7. Conclusions

Background and Motivation



Rainfall – triggers mudflows, but are soil particles and water the only components?



Gravity affects attachment of hydrophobic particles to *air bubbles*

UC San Diego
Structural Engineering
JACOBS SCHOOL OF ENGINEERING

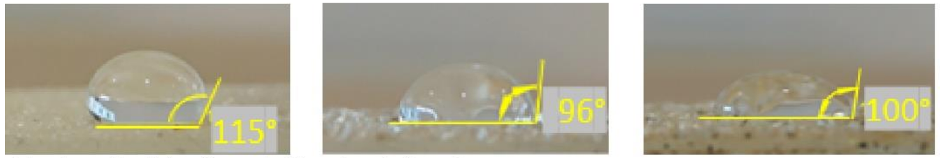
Materials and Methods

Materials:


Fine Otawa Sand


Medium Sand


Coarse Sand

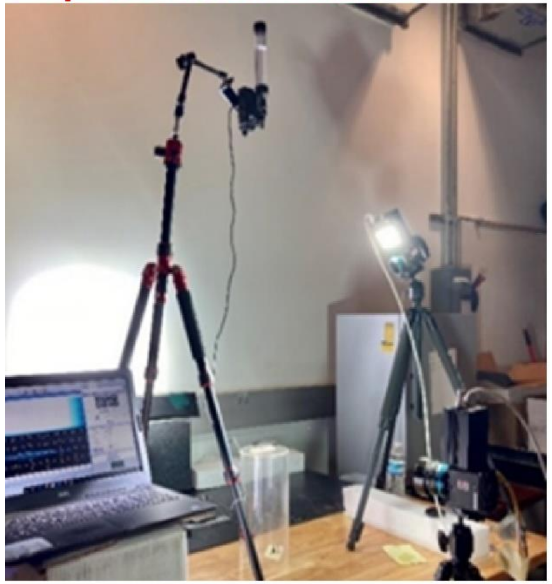


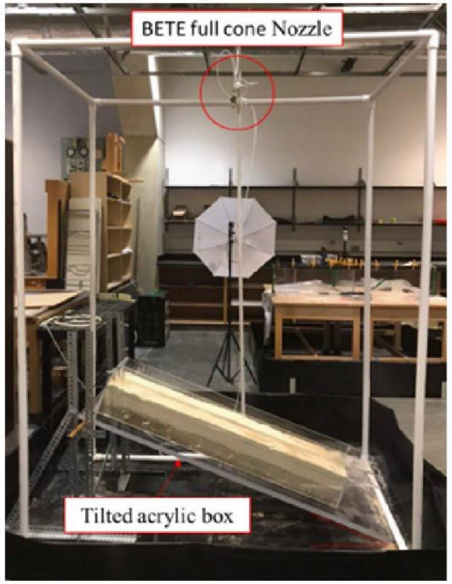
Hydrophobic Sand Contact Angles

- Single drop experiments on flat and sloped surfaces
- Fine, medium and coarse sand: regular and hydrophobic
- Silane treated sand in laboratory to make surface hydrophobic

Soil	Contact angle (°)		Cu	Cc	D10 (mm)	D30 (mm)	D60 (mm)
	Regular	Hydrophobic					
Fine	60	115	1.50	0.90	0.15	0.18	0.23
Medium	38	100	1.67	1.01	0.28	0.37	0.47
Coarse	27	96	1.53	1.03	0.46	0.57	0.70

Experimental Scales:


Single Drop Experiments



Laboratory Raining Experiments


Large Environmental Outside Flumes

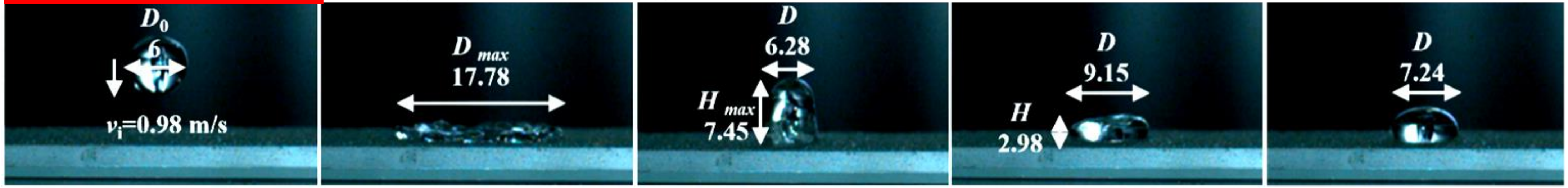
Upscaling:

1. Laboratory flume experiments with controlled raining intensity
2. Large outside flumes exposed to environmental conditions for 6 months

UC San Diego
Structural Engineering
JACOBS SCHOOL OF ENGINEERING

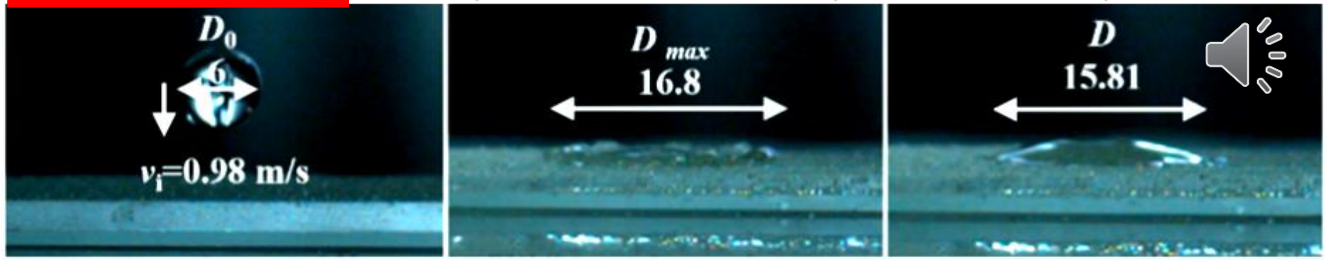
Single Raindrop Spread

Hydrophobic fine sand: Low impact 0.98 m/s velocity of a 6-mm drop



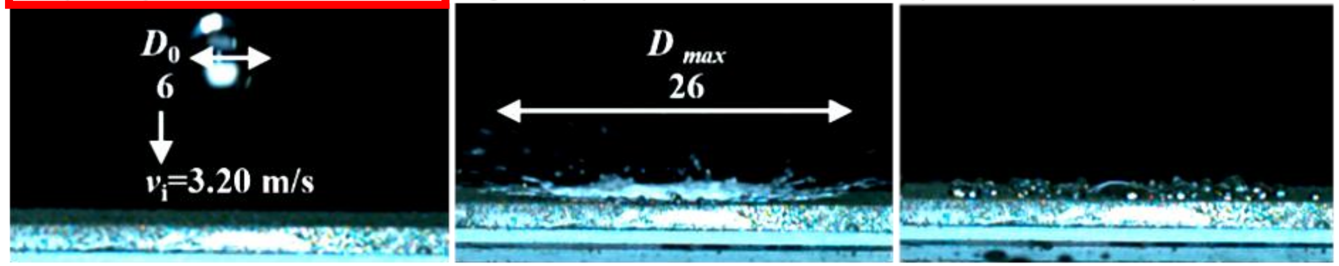
Impact | Max Spread | Rebound | Stabilization | Deposition

Regular fine sand: Low impact 0.98 m/s velocity of a 6-mm drop



Impact | Max Spread | Deposition

Hydrophobic fine sand: High impact 3.2 m/s velocity of a 6-mm drop

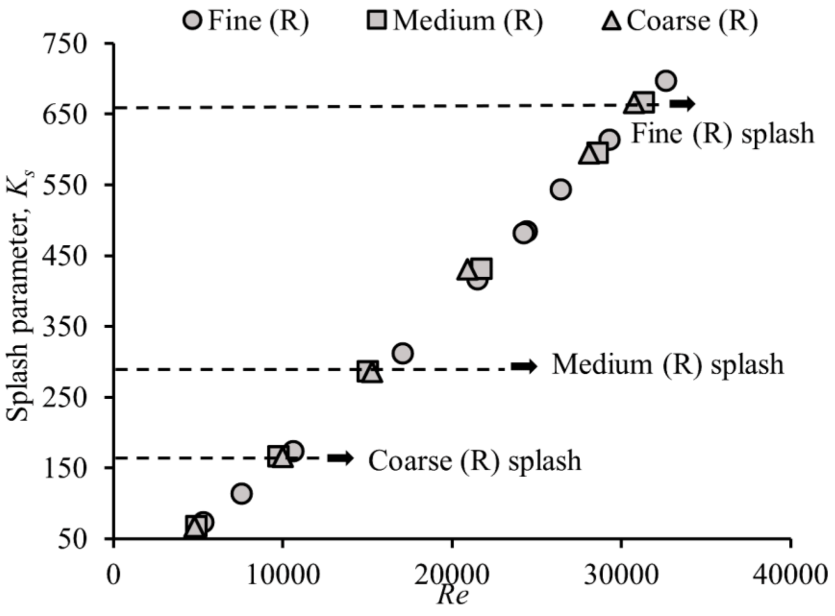


Impact | Max Spread | Detachment

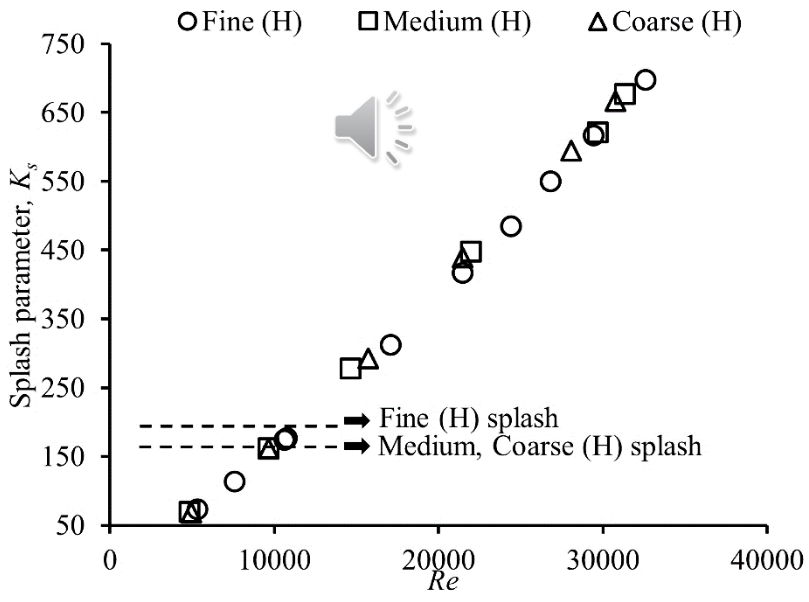
- Sand type and hydrophobicity change drop post-impact behavior
- Drop remains static and spread on regular sands
- Drop spread increases on hydrophobic surfaces and is not sensitive to grain size
- Drop retracts and bounces of hydrophobic sand surfaces at higher impact velocities

Single Raindrop Splash

- Splash threshold is lower for hydrophobic than regular sand
- Regular sand: splash threshold depends on the grain size
- Hydrophobic sand: the splash threshold is insensitive to the sand surface roughness



Regular sand



Hydrophobic sand

$$Re = \frac{\rho v D}{\eta} \quad \text{(Eq.1)}$$

$$We = \frac{\rho v D^2}{\sigma} \quad \text{(Eq.2)}$$

$$K_s = We^{1/2} Re^{1/4} \quad \text{(Eq.3)}$$

Re=Reynolds number
We =Weber number
ρ=liquid density
D=drop diameter
η=liquid dynamic viscosity
σ=liquid surface tension
v=velocity
K_s=splash parameter

Single Raindrop on Slope

Regular Fine Sand


Impact


Spreading


Rebound, Sliding


Arrest

Hydrophobic Fine Sand


Impact

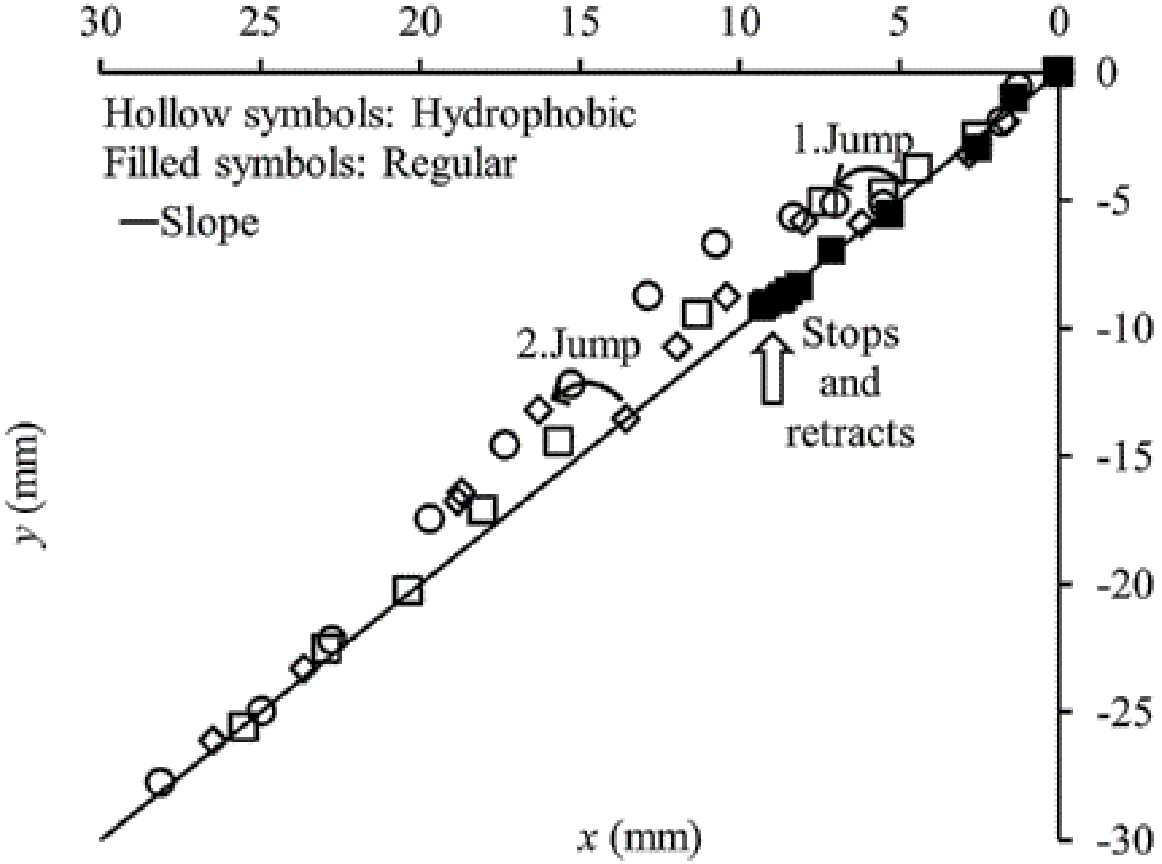

Spreading


Rebound, Sliding


Tail Formation


Jump


Rolling and Sliding



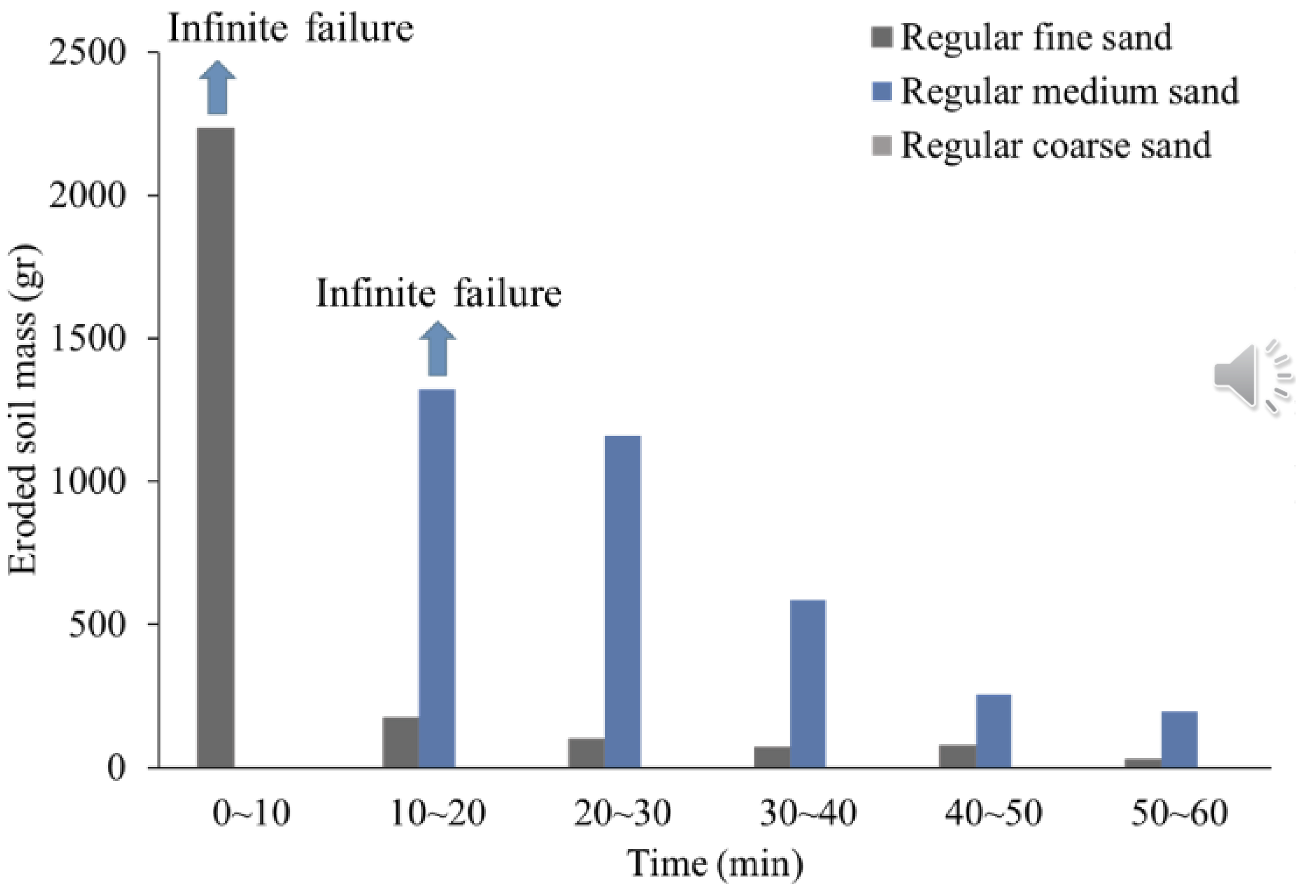
Drop falling on 45° slope with impact velocity of 0.98 m/s

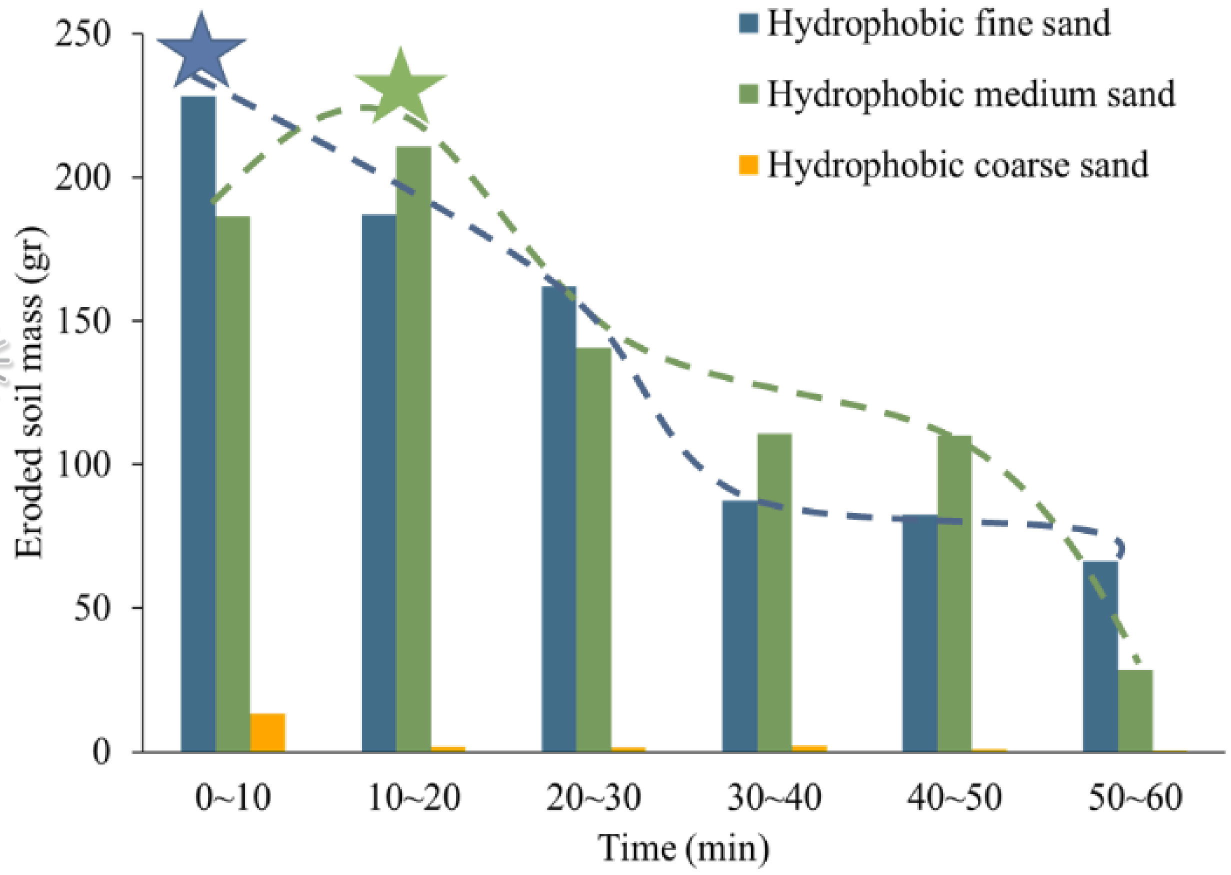
Erosion Under Rain Experiments

60 mm/h rain intensity, 30° slope

Erosion patterns on fine, medium, and coarse hydrophobic sand from left to right in the configuration

Sand Type Effect on Erosion Rates

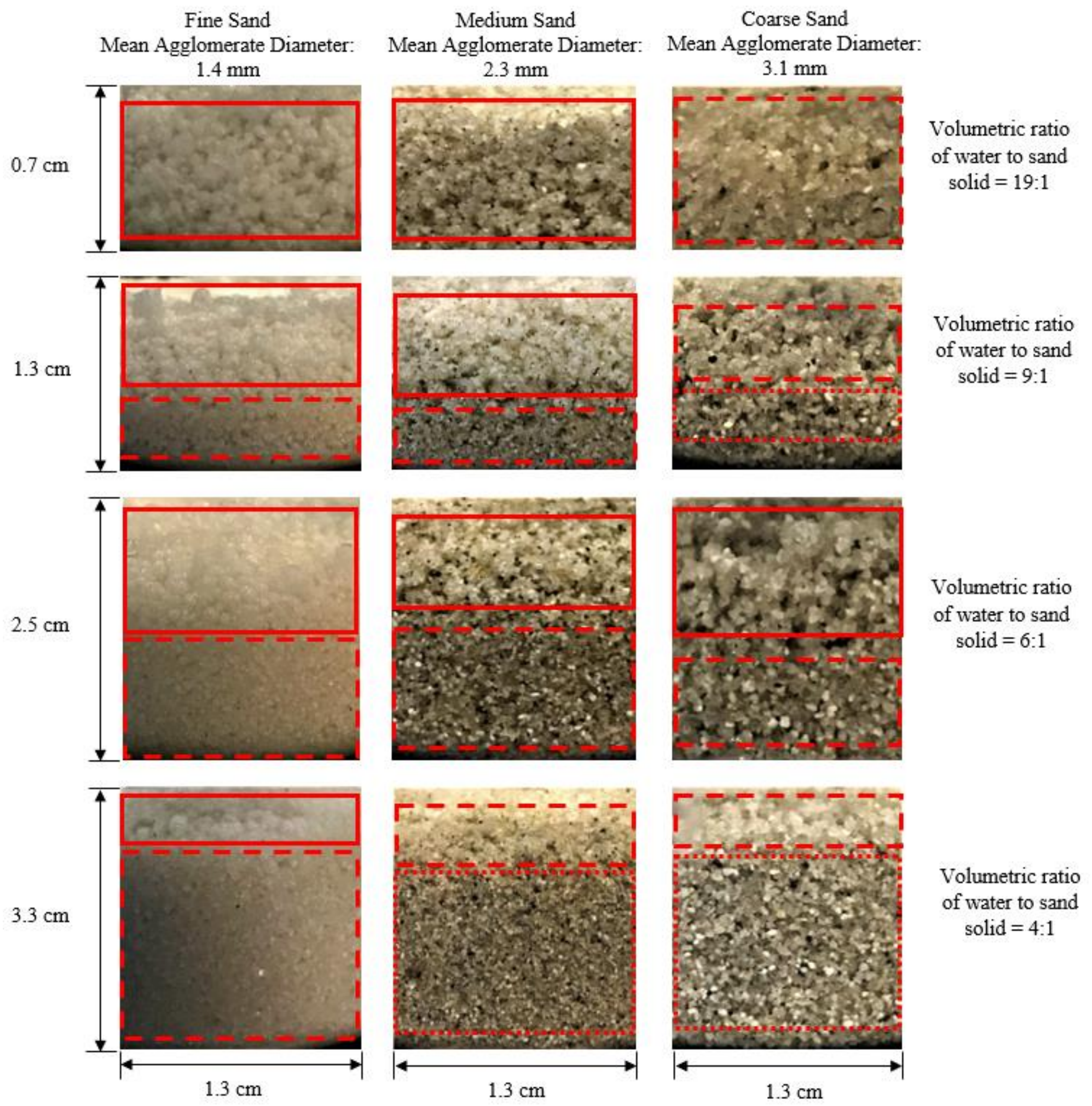




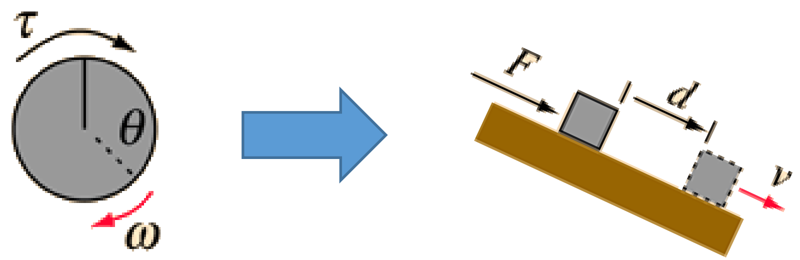
60 mm/h rain intensity, 30° slope

UC San Diego
Structural Engineering
JACOBS SCHOOL OF ENGINEERING

Mudflow Composition Experiments



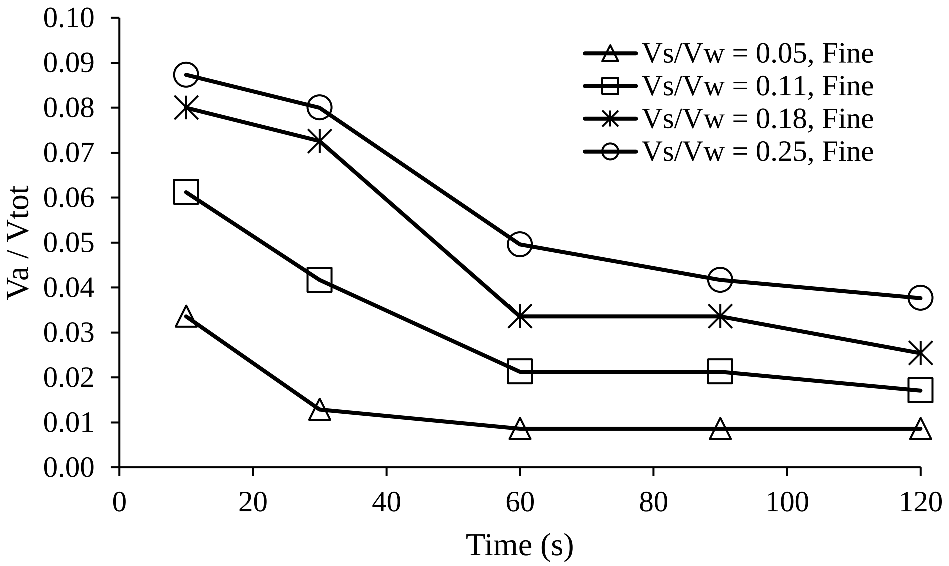
Mixing experiments with different blade rotation speeds to mimic downhill flow

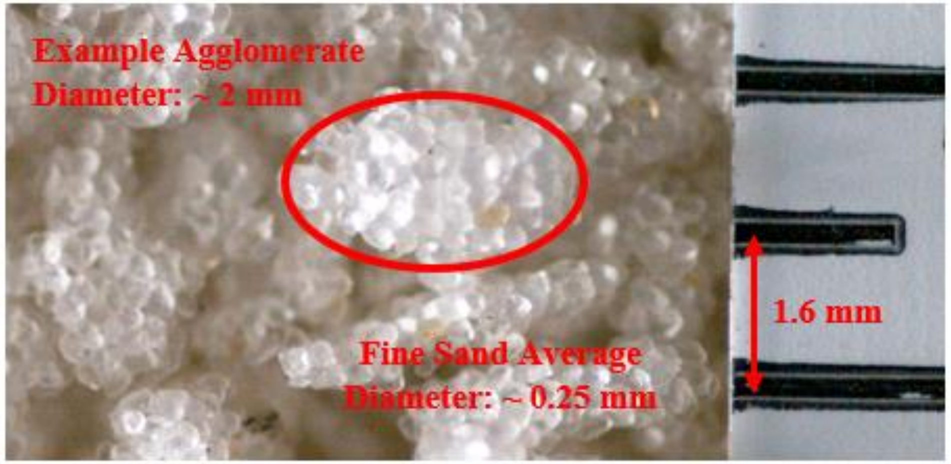


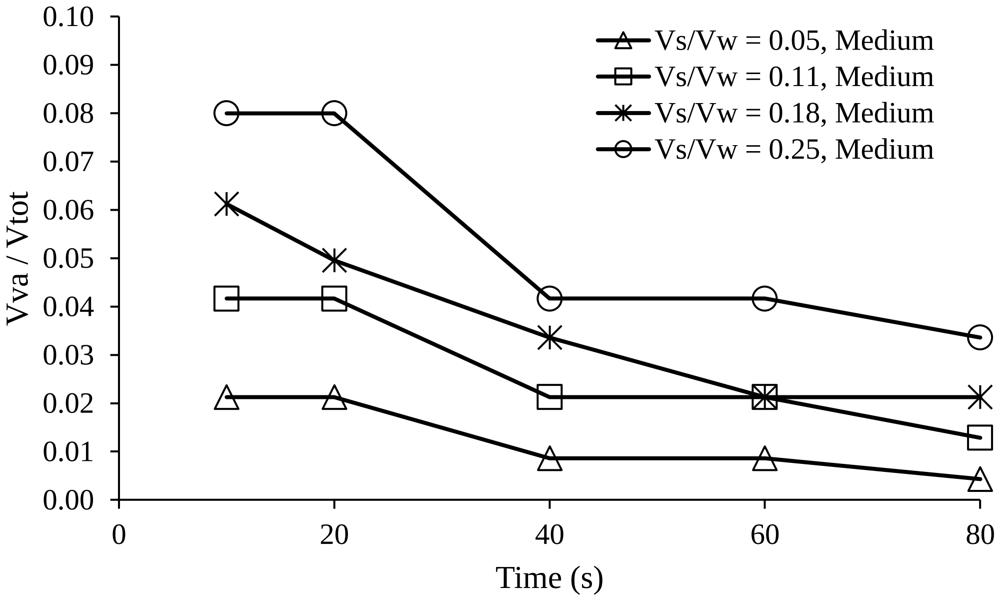
Mudflow mixture composition depends on sand type, air trapping, mixing speed and gravity

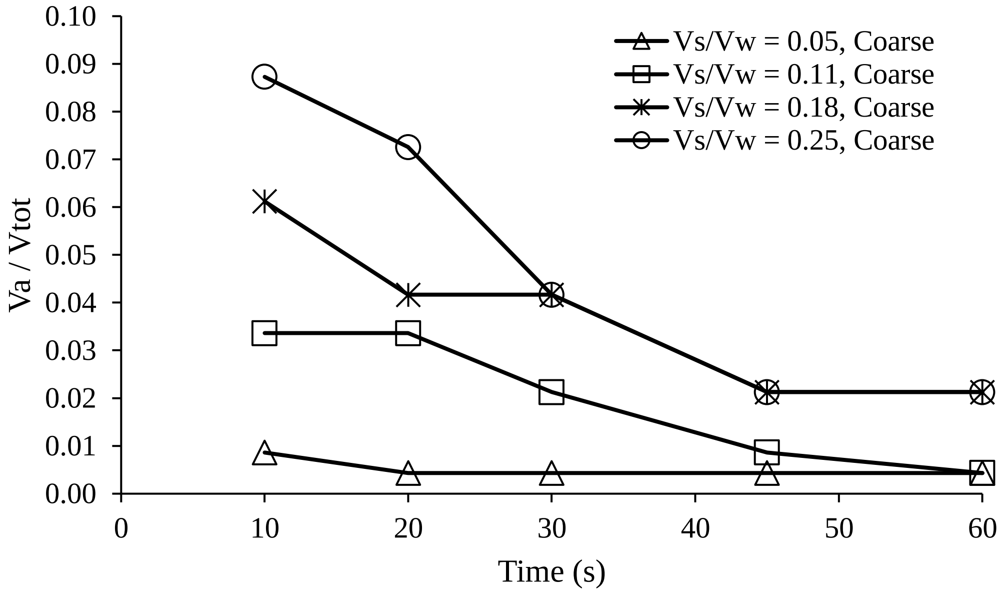
We assessed the conditions that affect amount of trapped air and agglomerate shapes and sizes

Assessment of Trapped Air

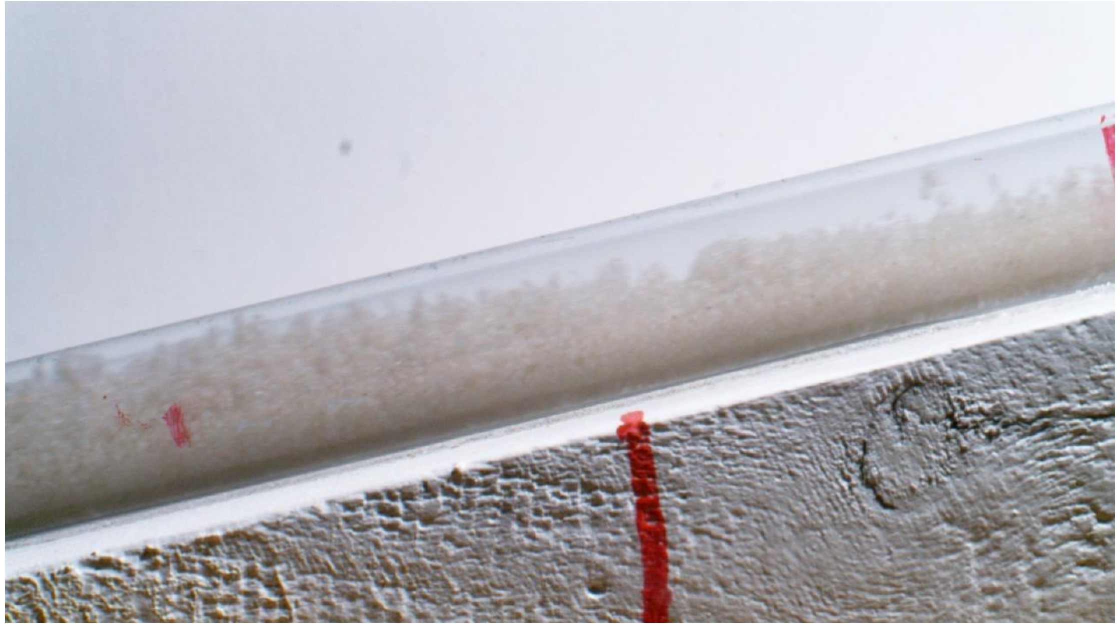




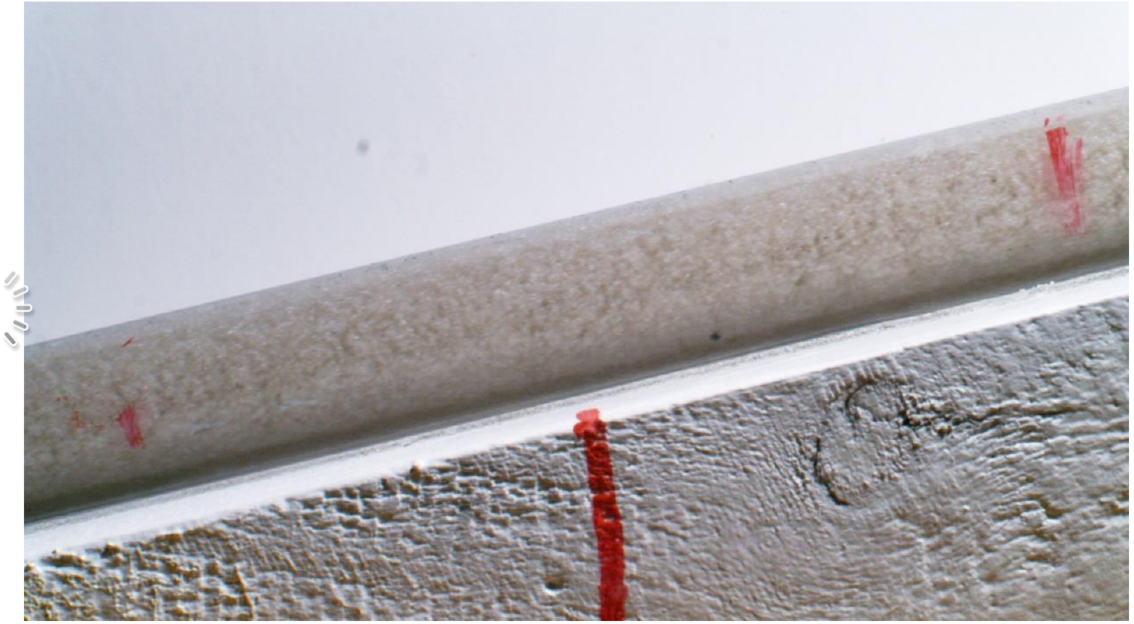




Mudflow Mixture Flow and Transport



Layered mixture flow and transport



Plug mixture flow and transport

Conclusions

- Wildfires induce hydrophobicity on soil grain surface, predominately on granular soils such as sands
- Across-scale experiments from a single drop impact towards raining experiments help better understand roles of different parameters on mudflow onset, flow and transport
- Soil surface dramatically affects a single drop post-impact behavior
- Drop rebounds, splashes and speeds down the hill more on finer sand compared to coarser sand, and hydrophobicity enhances it
- Water overflow and sand erosion is boosted with hydrophobicity and smaller grain size
- Environmental experiments reveal cascading response of the burned surface, once an initial rain induced post-erosion channels on surface, less intensive rains yielded enhanced sand erosion and water overflow
- Surface morphology is constantly changing and affects erosion risk for the subsequent rain event

Thank you for your attention!

Contact:

Dr. Ingrid Tomac
Assistant Professor
Structural Engineering Department
University of California, San Diego

http://ingridtomac.eng.ucsd.edu

9500 Gilman Drive #0085
La Jolla, CA 92093-0085
Office: SME Bldg. Room 445D
Phone: (858) 822-3009
Mobile: (303) 803-5781