Future of Army Terramechanics

Capabilities and Needs

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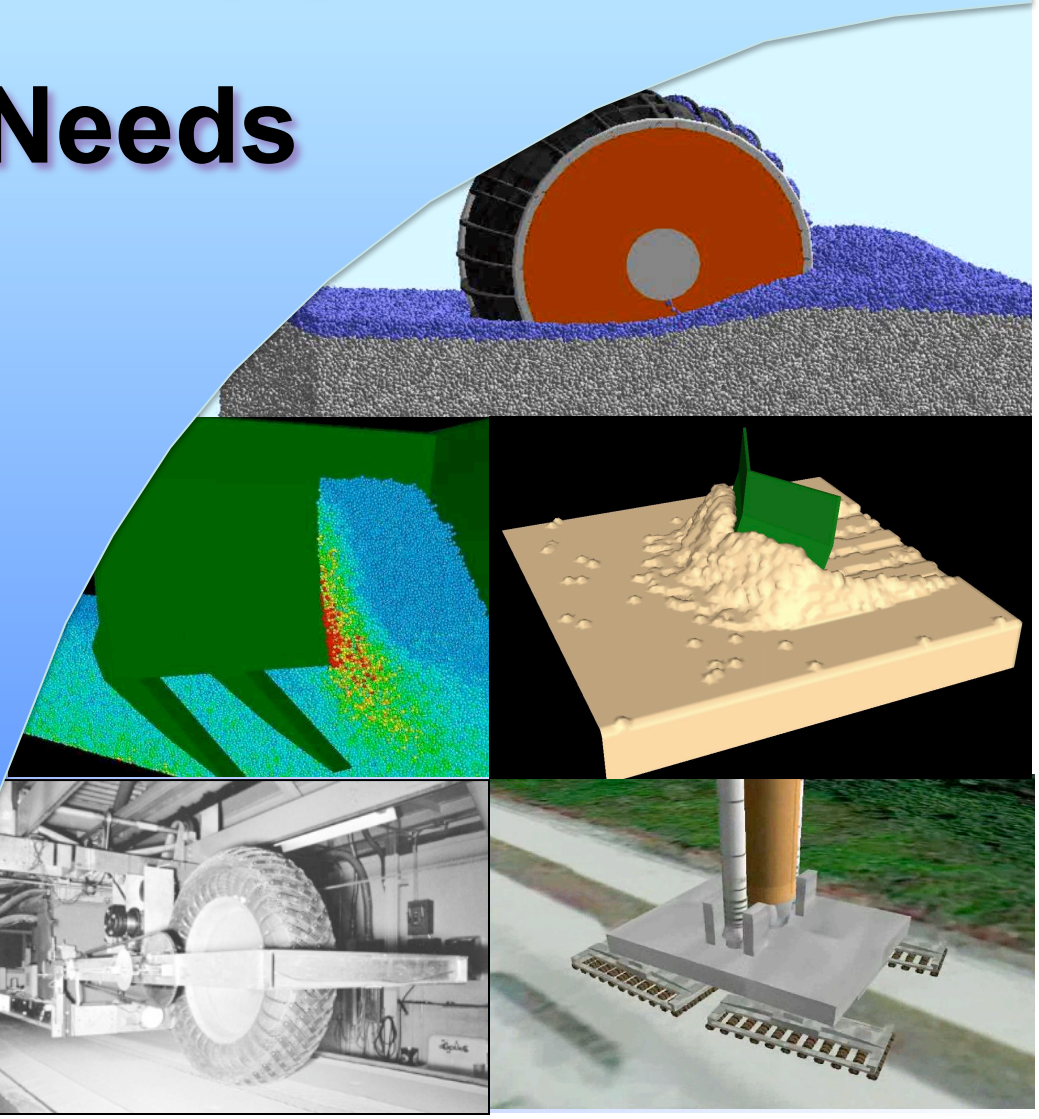
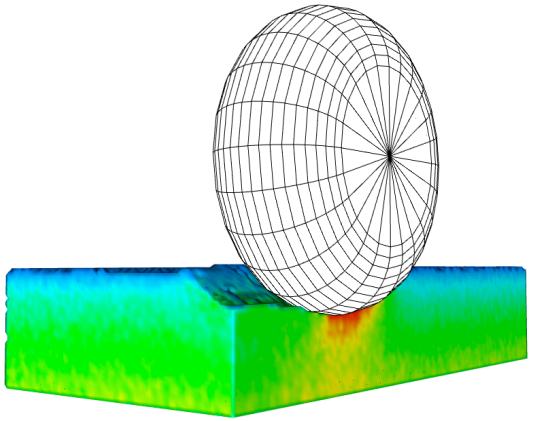
US Army Corps of Engineers
BUILDING STRONG®



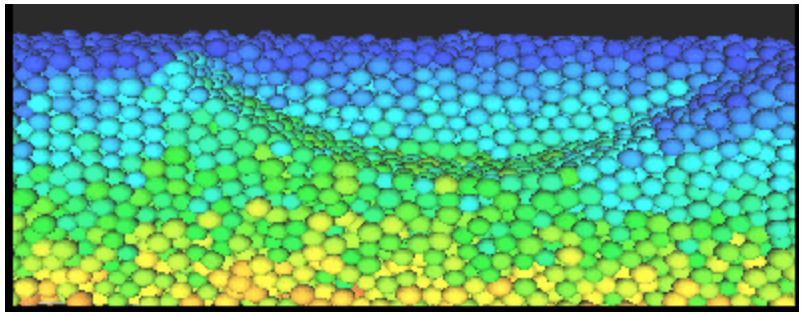
Outline

- Background on ERDC contribution to Army Terramechanics
- A little history
- Recent research efforts
- Thoughts on capabilities and limitations of computer simulation
- Concluding Remarks



Background

- ERDC consists of seven laboratories located at four campuses
- Various field sites
- Two labs concentrating on mobility
  - Mobility Systems (GSL-Vicksburg)
  - CRREL (New Hampshire)



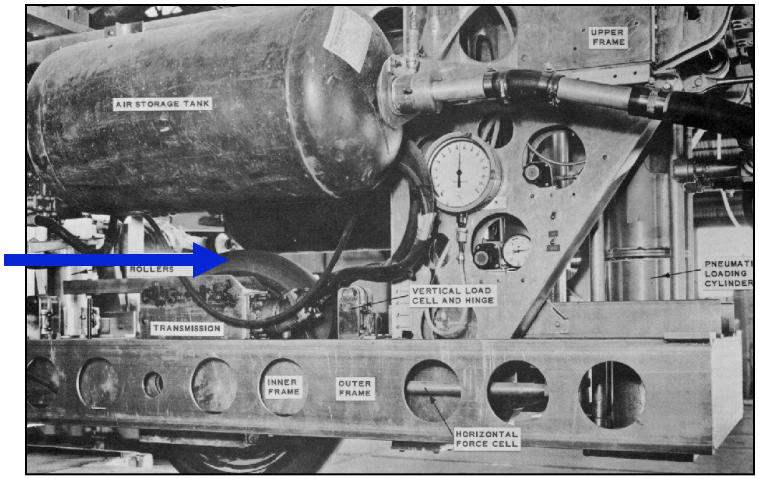

Army Vehicle Mobility

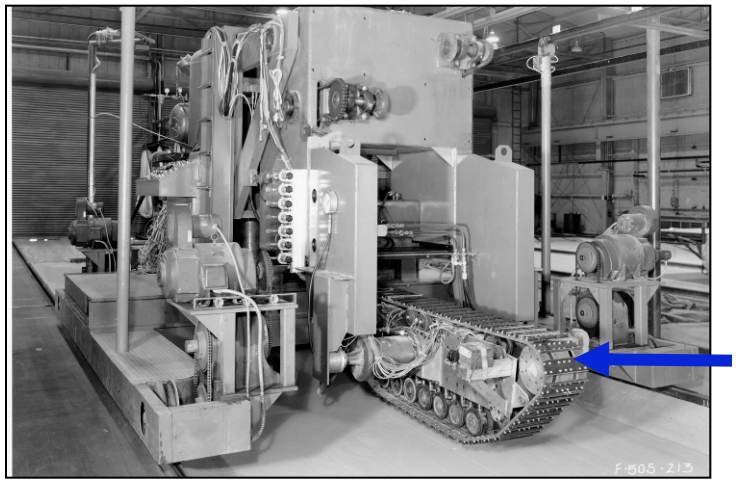
ERDC Mobility Research

- Dedicated mobility group since the 1950s
- Vehicle testing
- Mobility models (NRMM)
- Historically, mobility research performed by the WES and CRREL.
- Computer simulation taking on greater role

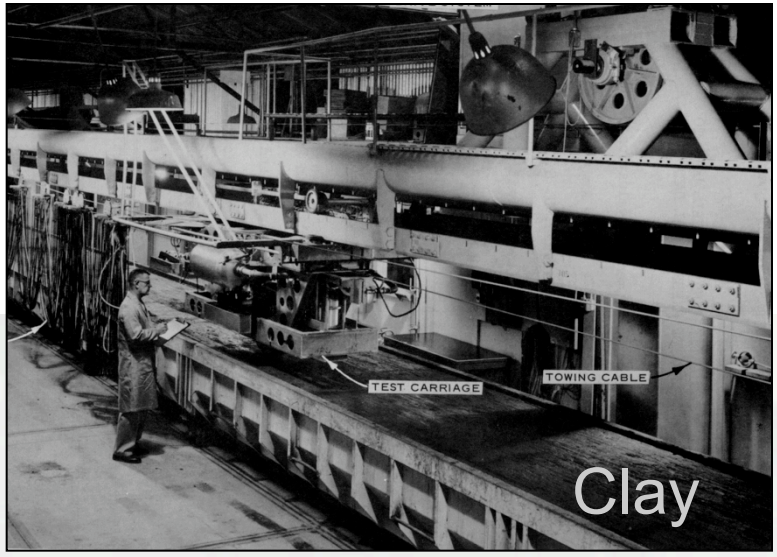
Historical Support to Apollo Program

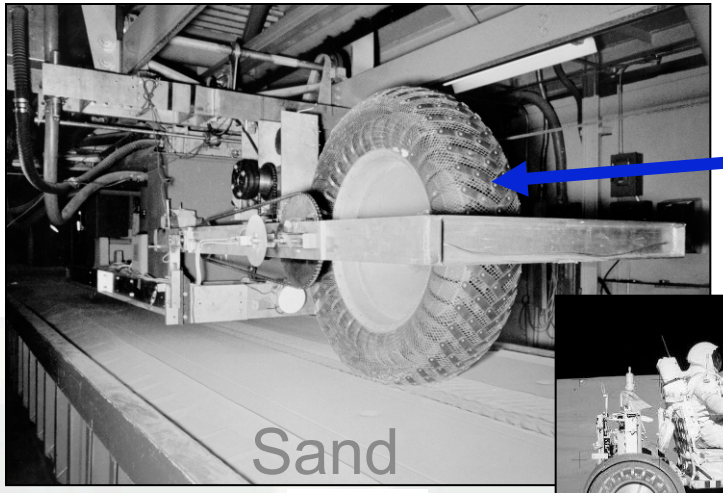
Single Tire



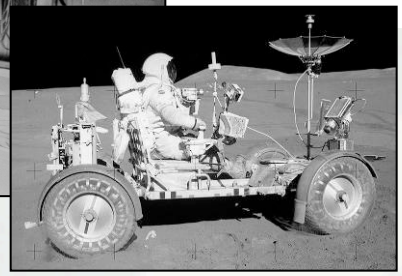


Single Track



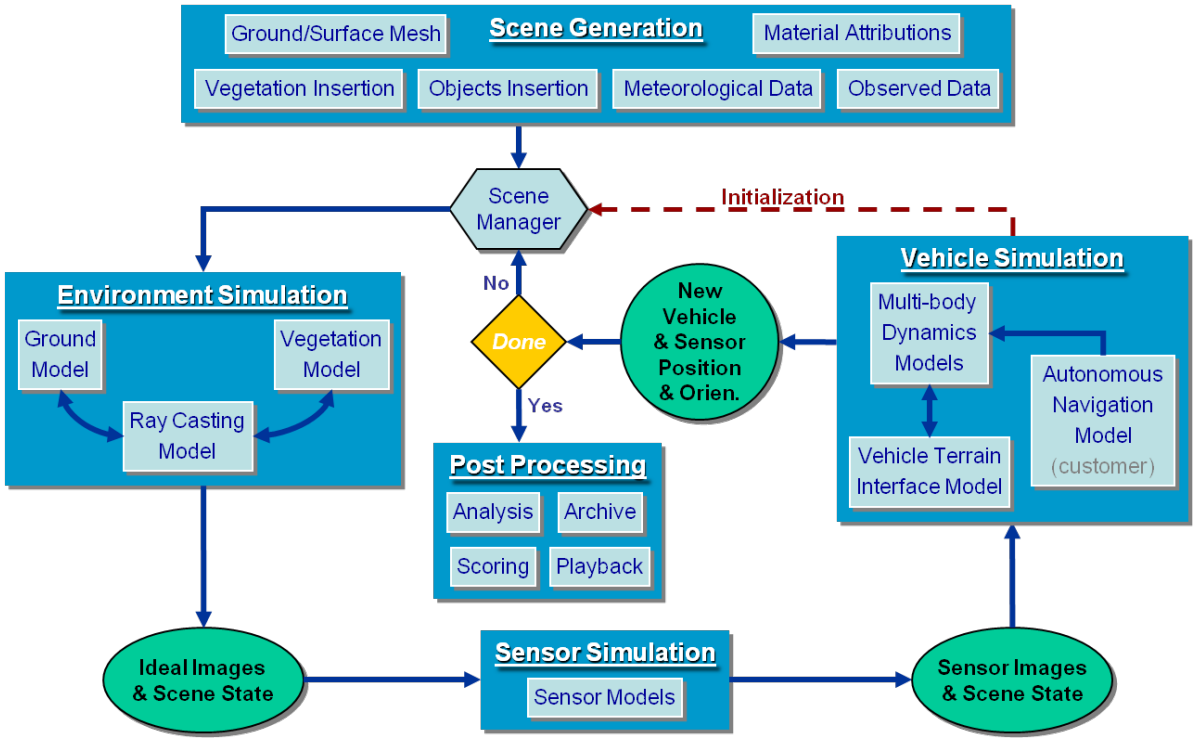


Apollo Lunar Rover Tire



VANE Computational Testbed

- **Support UGV design trades and performance evaluations**
  - Autonomy systems and algorithms for mobility/ navigation
  - Sensors for robotic perception and localization
  - Vehicle platforms and components
  - Tactical behaviors
  - Tactics, techniques, and procedures (TTPs)



- **Integrates high-fidelity models for environment, terrain, vehicles, and sensors**
- **Core product simulates geoenvironmental influences on sensor responses and UGV platform mobility**

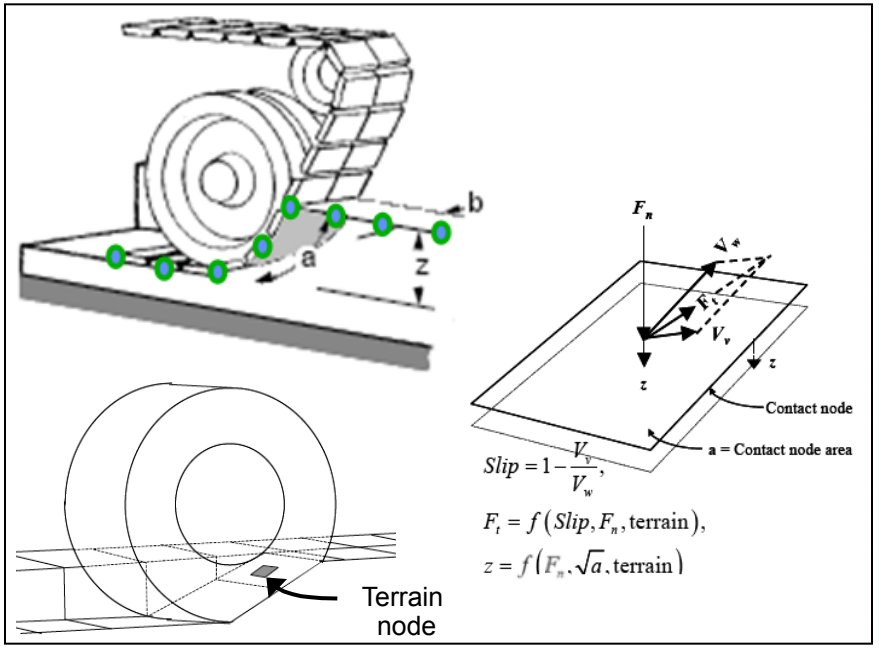
ANVEL - 'Face' of the VANE CTB

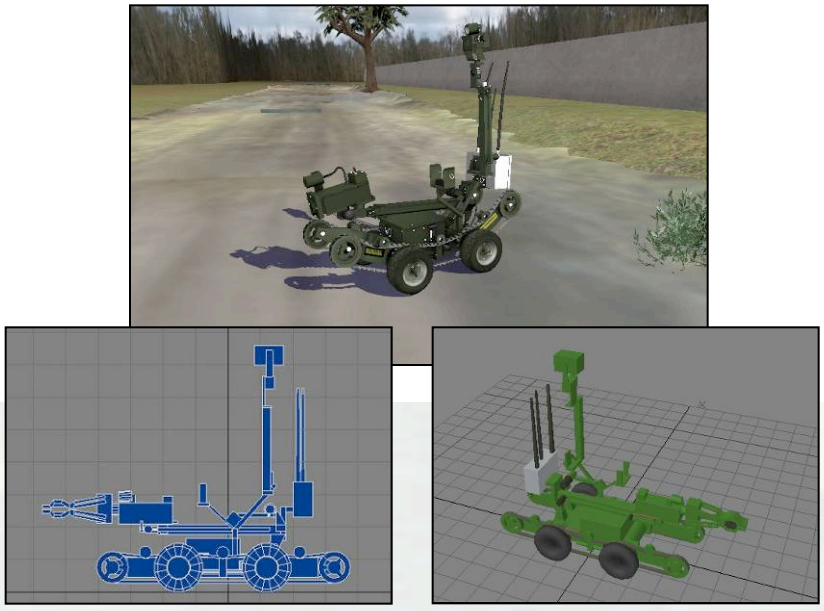
Features of ANVEL

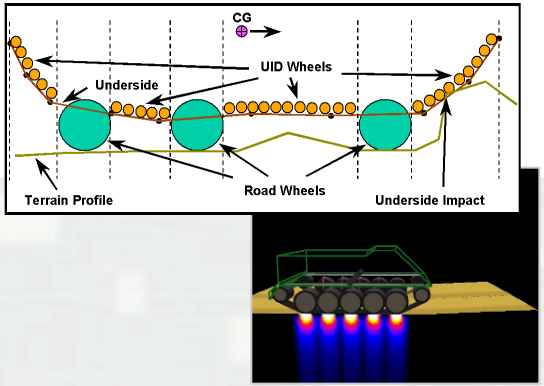
- **3-D vehicle dynamics simulator designed for the VANE CTB**
  - Pre-simulation planning and post-processing visualization
- **Uses the Open Dynamics Engine (ODE) for multi-body physics**
  - Simulates all vehicle components except for the wheels and tracks
- **Uses the Ground Contact Element (GCE) with the Vehicle Terrain Interface (VTI) model to simulate the interaction forces on wheels/tracks**
  - Longitudinal and lateral traction, motion resistance, and sinkage

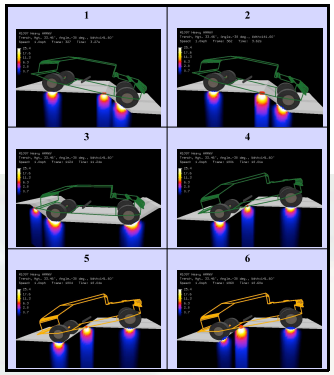
VANE CTB Terramechanics

- Emerging implementation for vehicle-soil relationships in vehicle dynamics software
  - Vehicle Terrain Interface (VTI) model
    - Nodal-based terramechanics for wheels and tracks
  - Ground Contact Element (GCE)





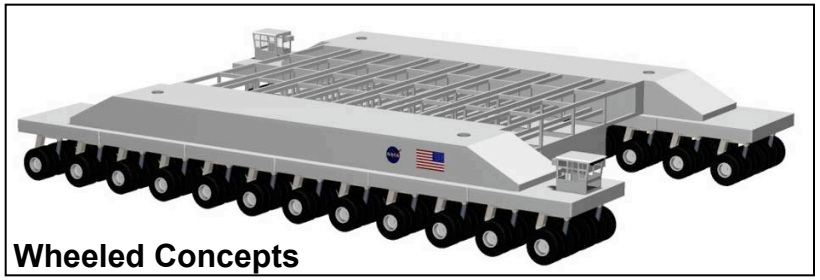


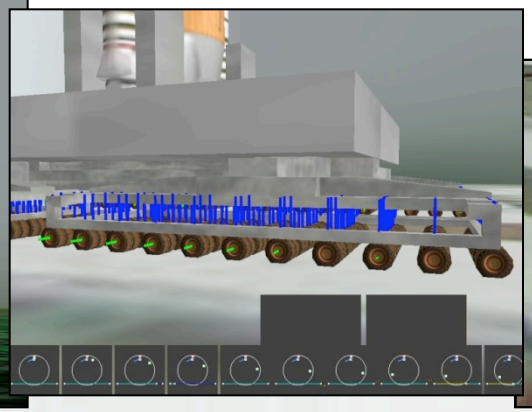


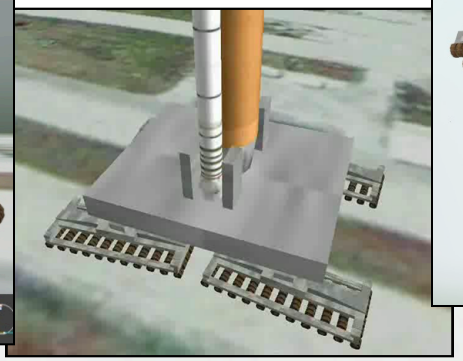
NASA Crawler Transporter Study

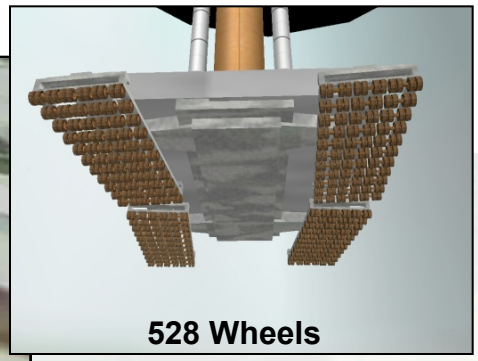
- Study to investigate crawlerway compatibility for Ares V Crawler Transporter concepts
  - Analytical assessment of four wheeled crawler concepts to replace aging tracked platform
    - Concepts have 80, 192, 224, and 528 pneumatic tires
  - High resolution model of most complex concept
    - Early application of GCE with VTI in ANVEL Software


Current Tracked Crawler


Wheeled Concepts





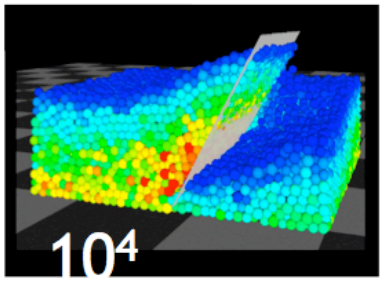

528 Wheels

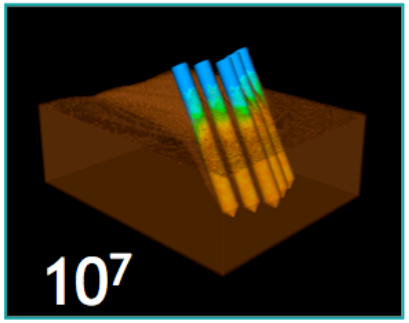

Granular Mechanics

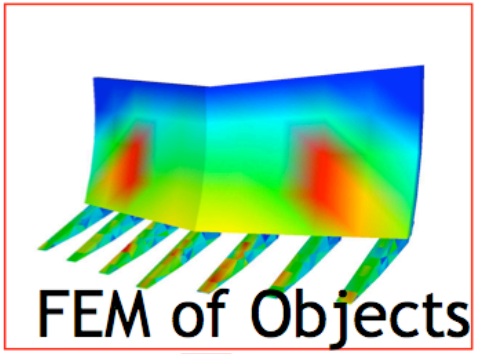
DEM at ERDC

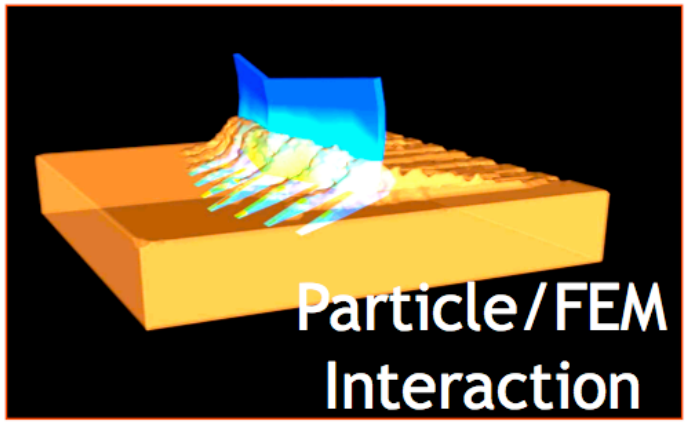
- (70s-80s)WES used Cundal's model for rock mechanics.
- (80s) Used home-grown codes (Palmerton)
- (90s-present) CRELL developed DEM for solving numerous application in Ice and Snow mechanics (Hopkins)
- (90s) Supported development of DDA (Shi)
- (90s-present) WES/ERDC developed granular mechanics research as extension to research on constitutive relationships on soils.

ERDC Large-Scale Computing DEM Work



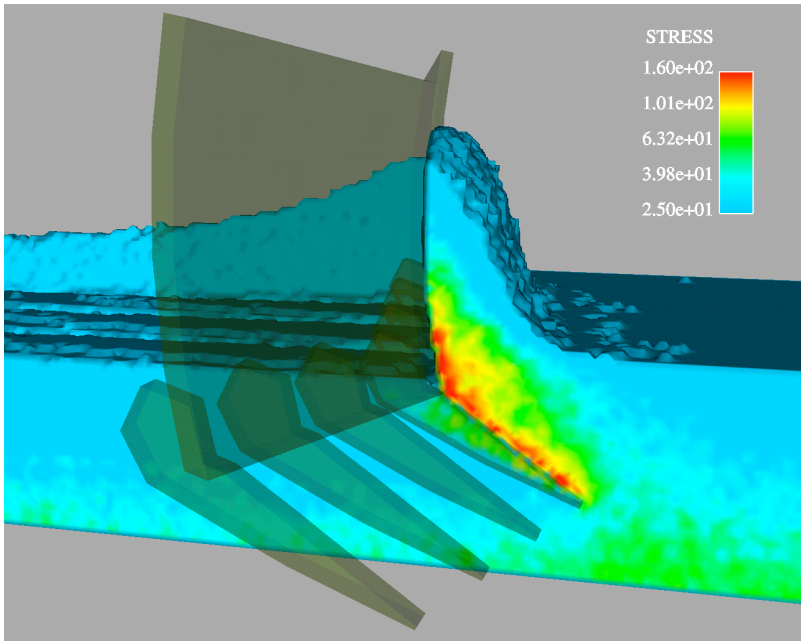




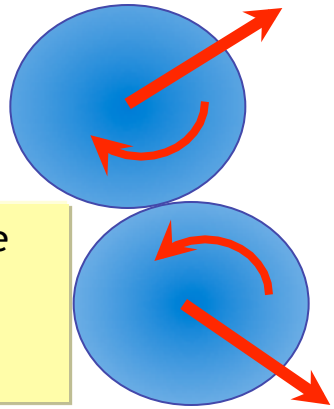


Horner and Carrillo
Circa 1996

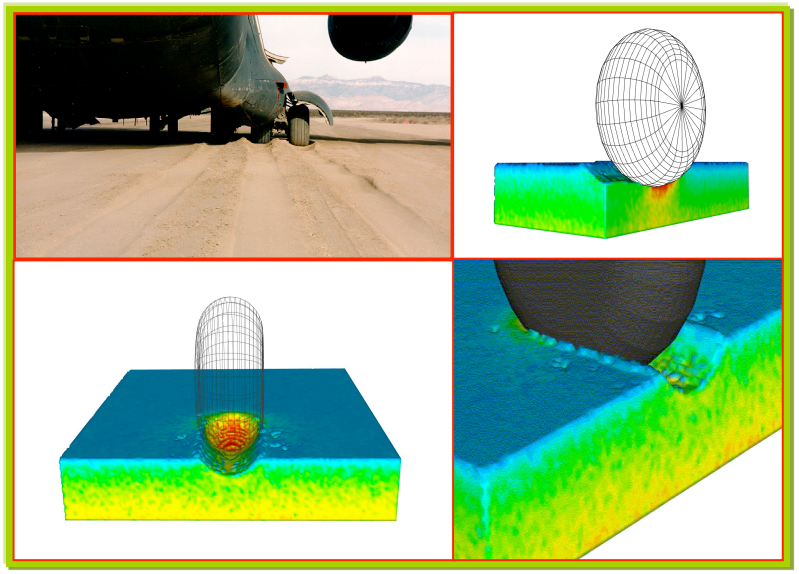
The computational solution

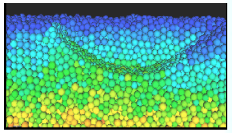


- The discrete element method depends on high performance computing resources.



- Discrete element models are fundamentally simple but display realistic *emergent* behavior.



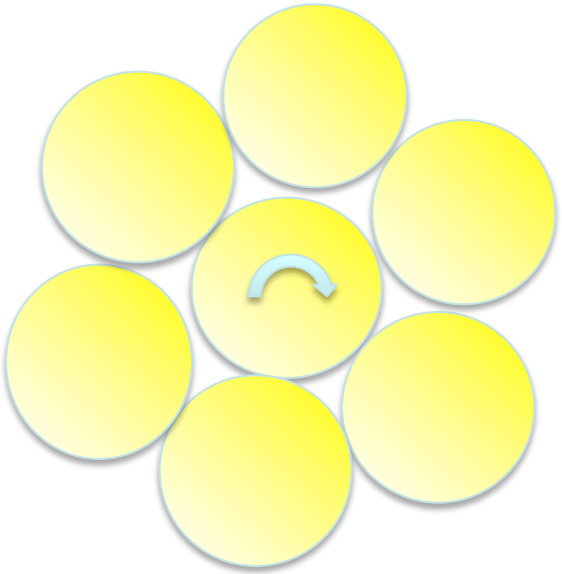


- DEM is in its formative stages but with HPC support will become a powerful analysis tool

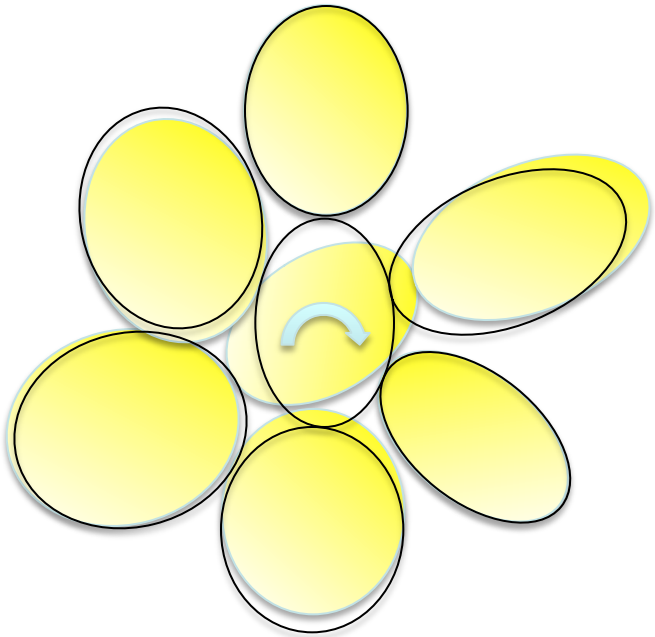
Simulation Details

Non-Spherical Particles

- Rotation resistance derived from non-spherical particles fundamentally different from that derived from rotational resistance at contact.



Rotation within own volume

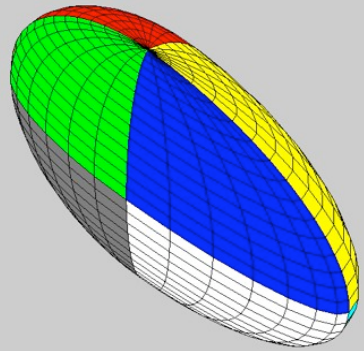


Rotation and volume change

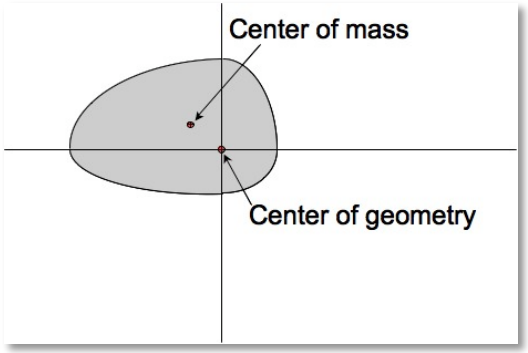
Simulation Details

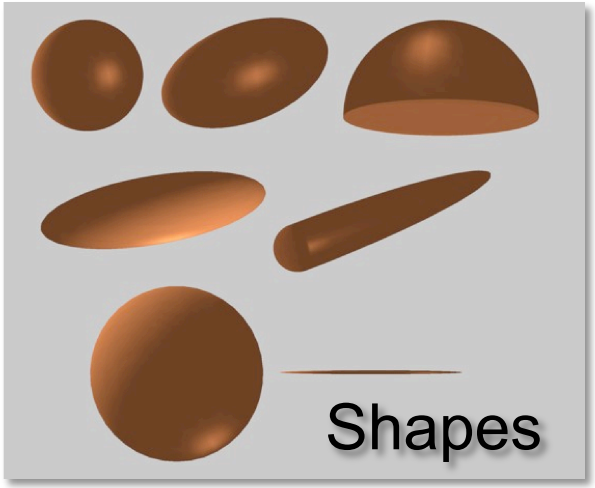
Poly-Ellipsoid Particles

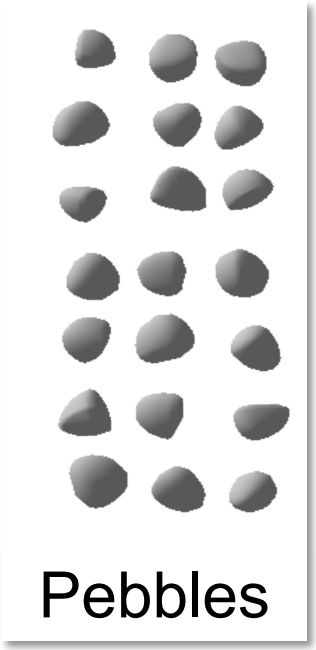
- Non-spherical particle readily implemented into any DEM code for ellipsoids.
- Peters, Hopkins, Kala and Wahl (2009), *Engineering Computations*



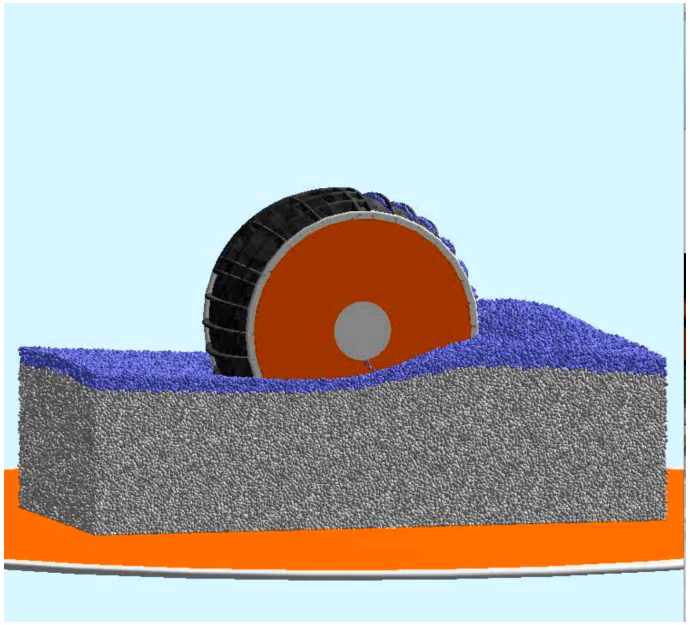
Compound surface: Each color represents a different ellipsoid patch





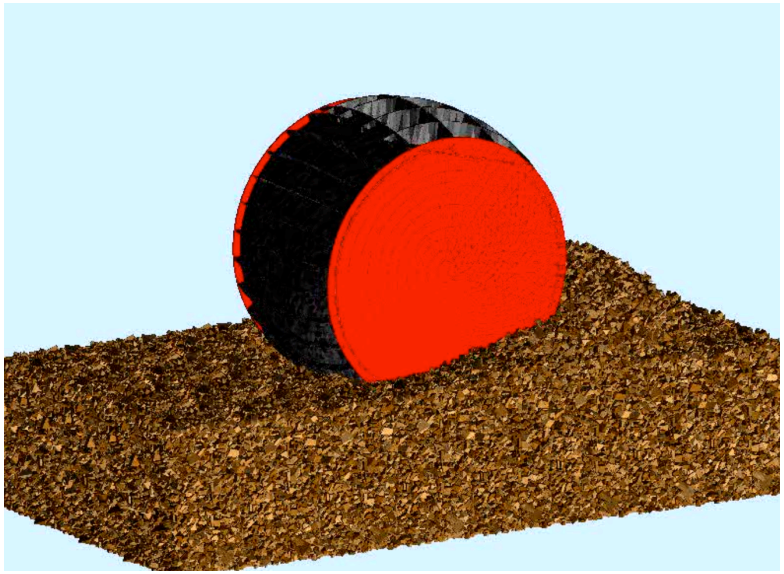


Recent Work by Hopkins



Ploy-ellipsoid particles

Polyhedral particles



Limitations and Research Needs

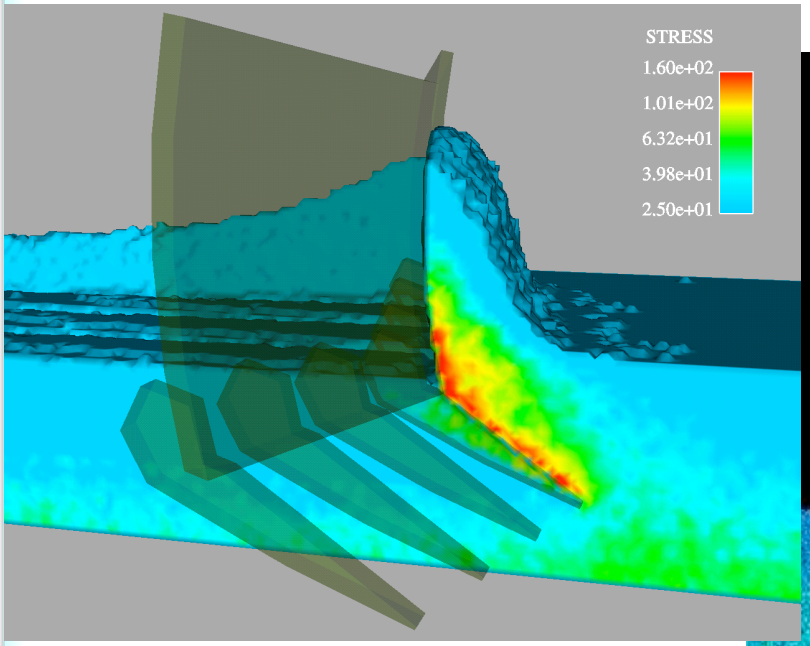
- Application of DEM has an inherent limitation caused by the linkage between time and spatial scales – the smaller the length the shorter the time that can be modeled.
- Better understanding of the convergence of the method.
  - Theory not available for DEM systems
  - Softening of particles gives limited advantage, increasing mass not at all
  - Centrifuge-style scaling must account for size effects

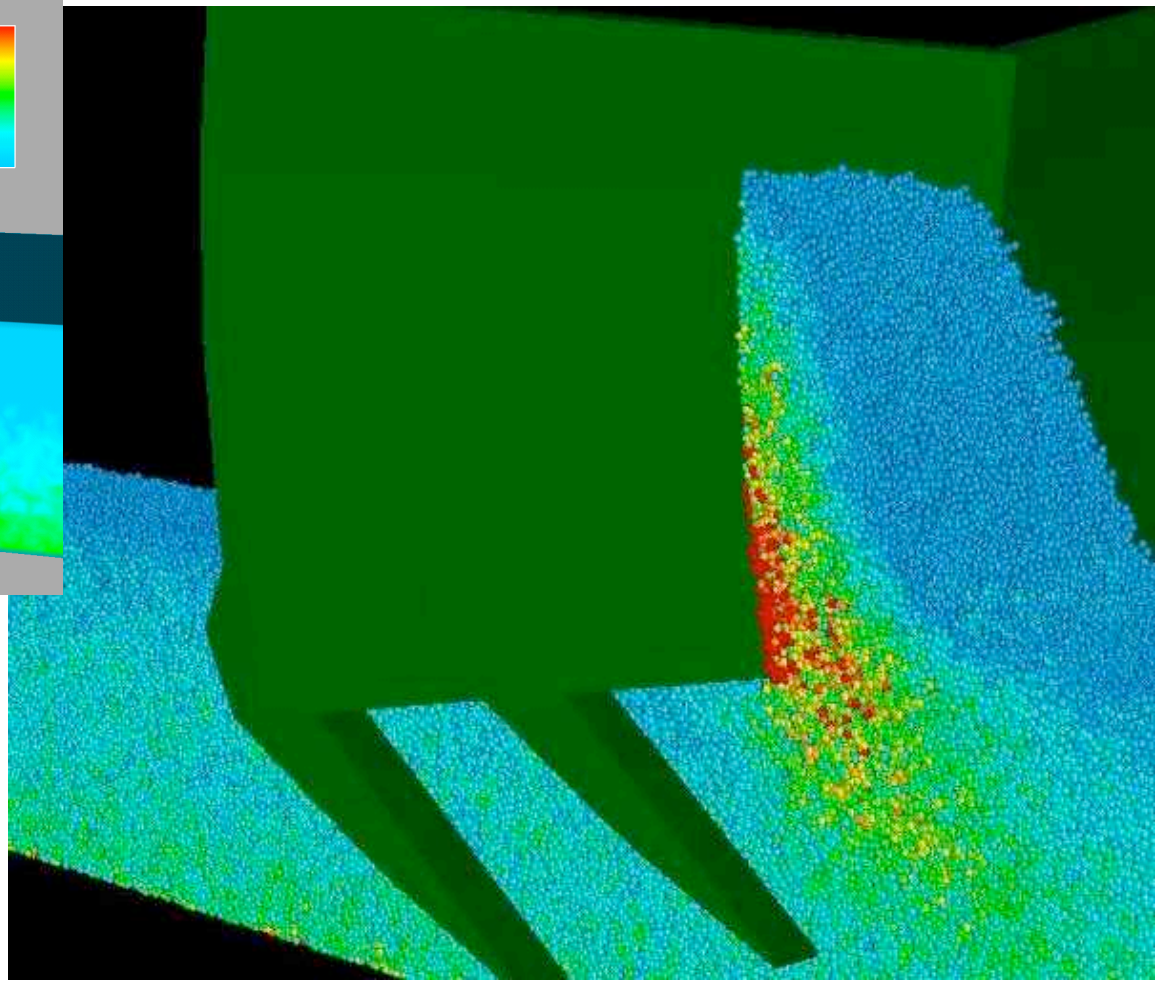
Principal Themes

1. You cannot compute what you do not resolve. *The Numerical Sage*

2. Numerical error appears as real physics but at the wrong scale.

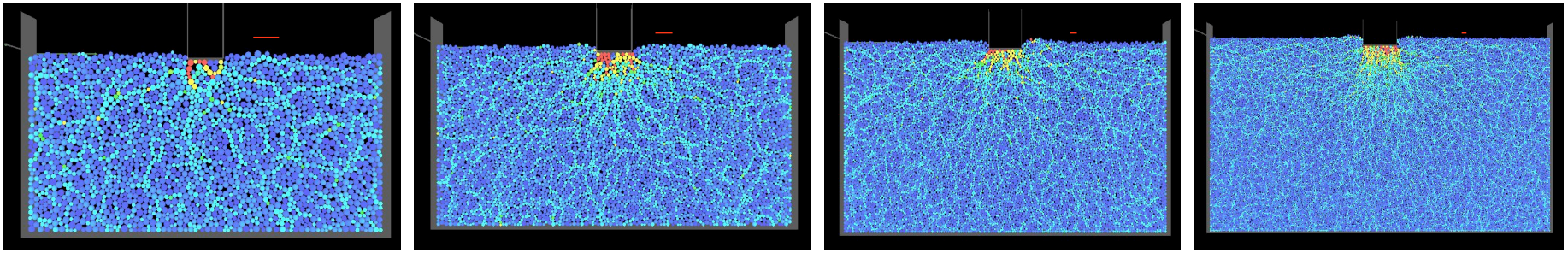
The Particle Scale

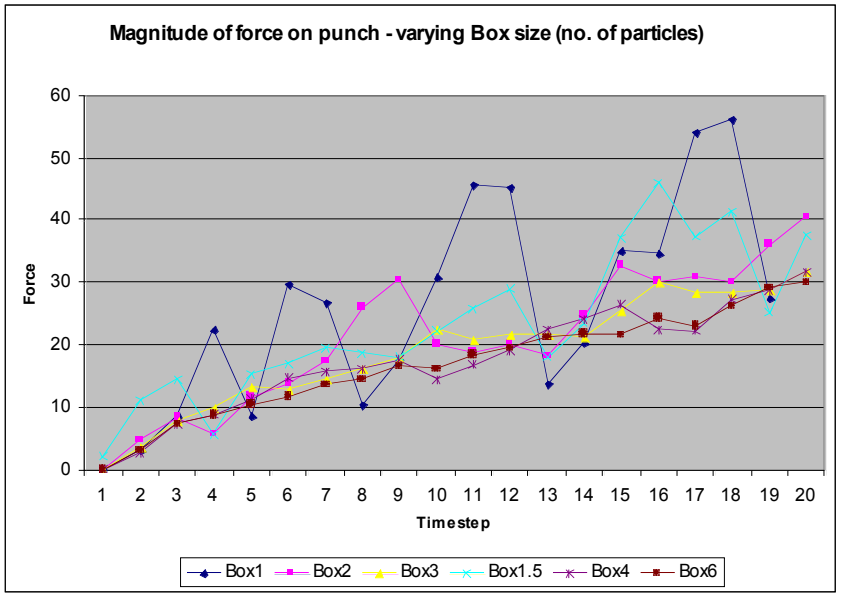


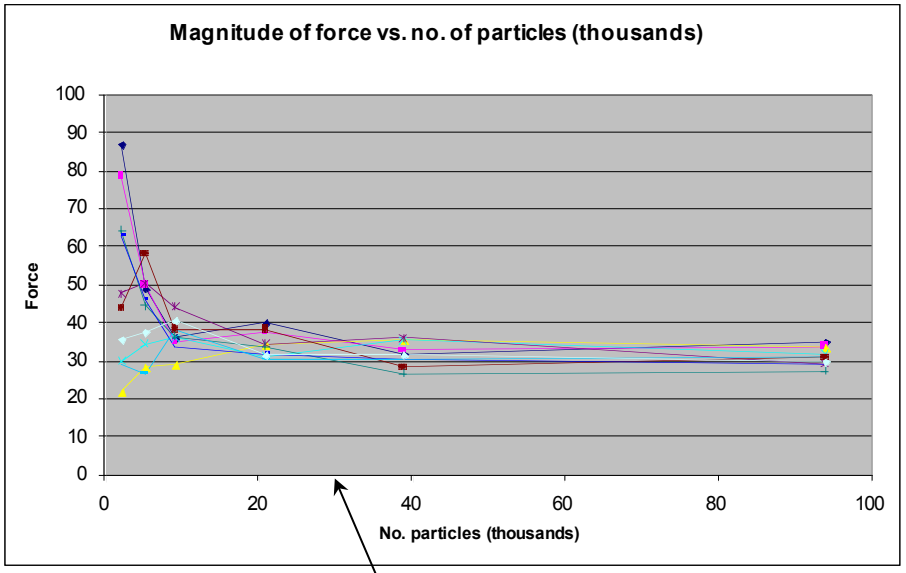


Cutaway View of Discrete Element Simulation of Plowing in Soil

Calibration Issues and Convergence

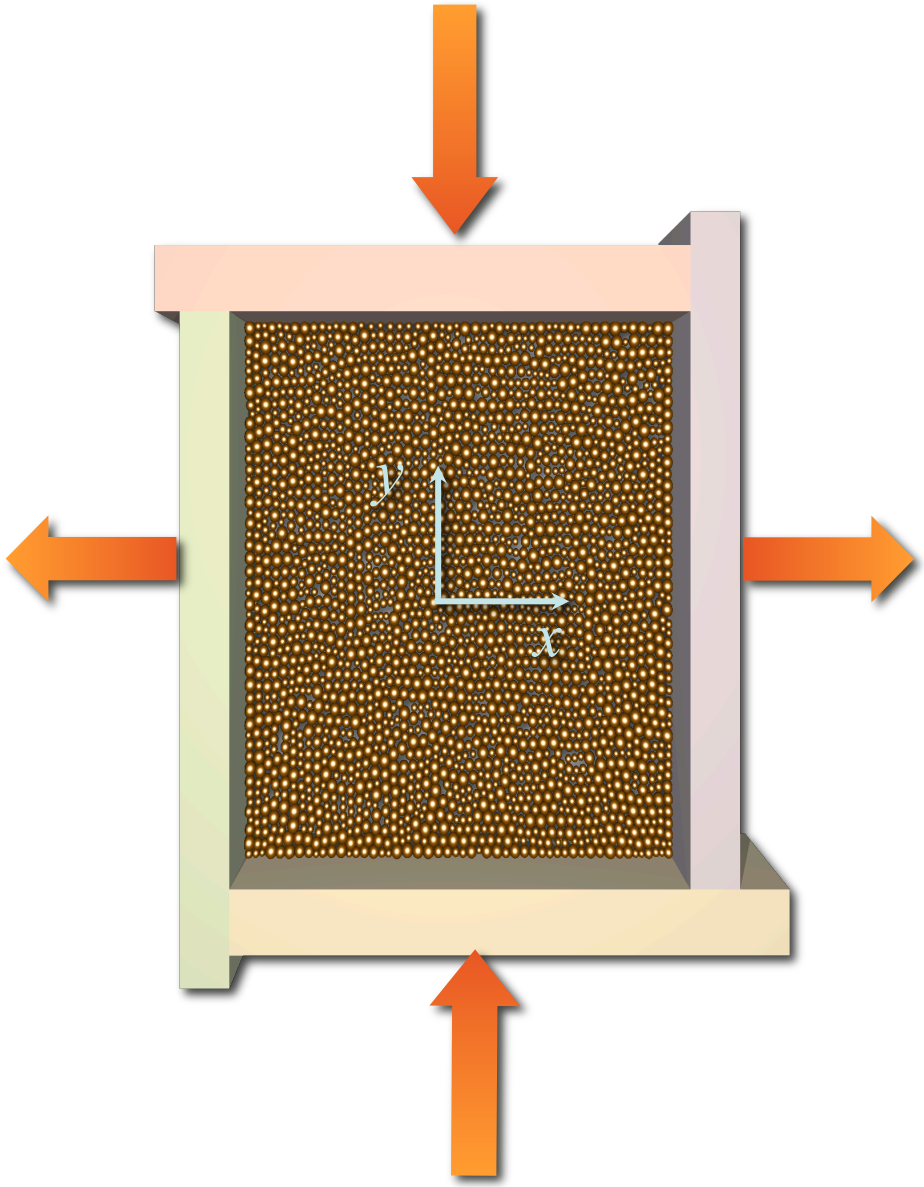




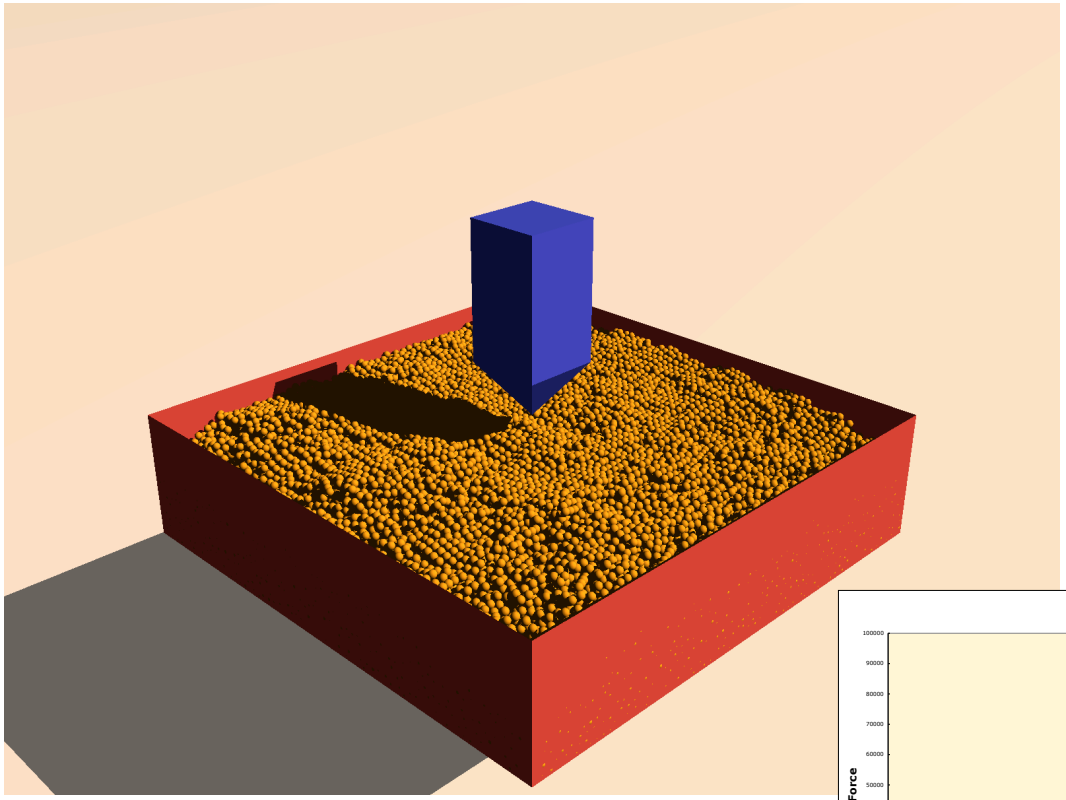


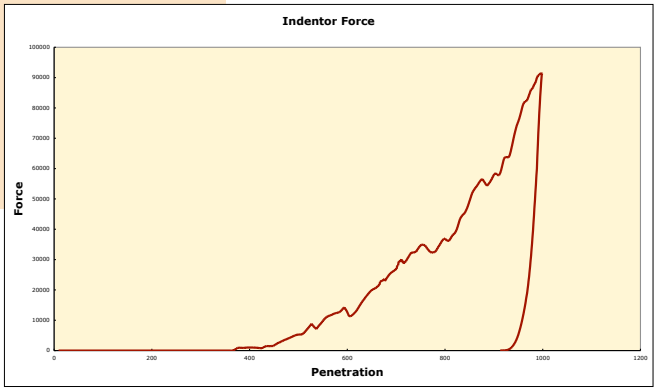
6.4 million for 3D

Materials Research



New Directions: Nano-Scale Granular Media



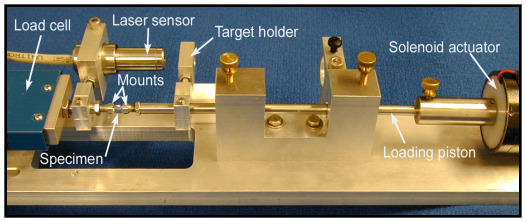


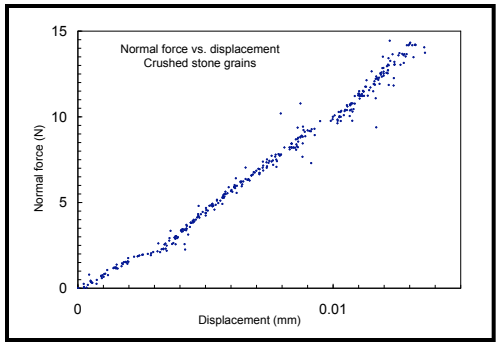
C–S–H phase of Portland cement

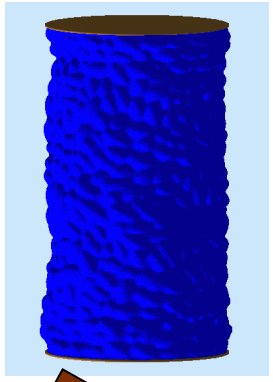
Soil Mechanics in Space Science

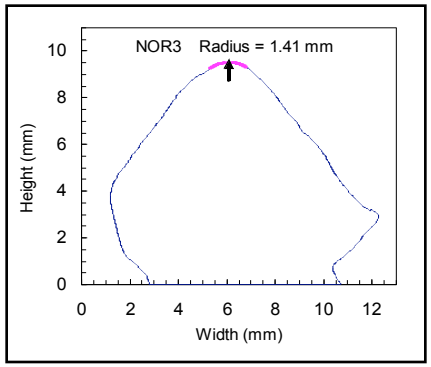
- Must be careful applying soil mechanics derived from earth experience to other environments
  - Weathering (or lack thereof)
  - Lack of atmosphere
  - Surface charge
  - Initial condition
- DEM can make its greatest contribution in understanding space soil mechanics

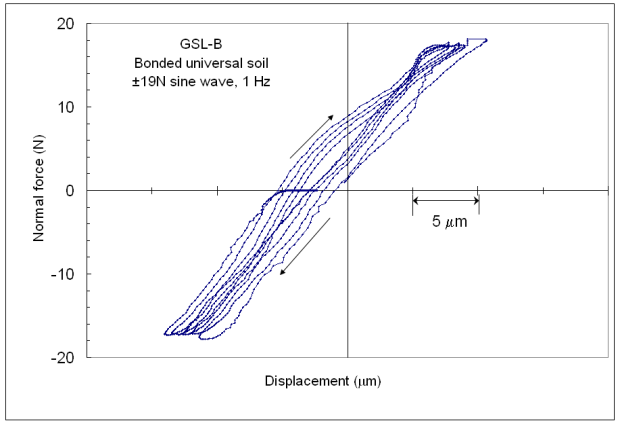
Grain-scale Studies and Media Simulation (CRREL)

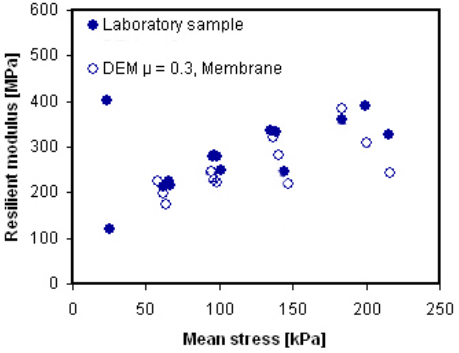












Cole and Hopkins


Concluding Remarks

Concluding Remarks

- Suite of models needed
  - Small scales (DEM) to understand granular mechanics
  - Large scale (Anvil) for mission evaluation
- DEM can contribute to understanding engineering properties of materials we can't test


Questions