목차

ROCKY tSNE

1. ROCKY 소개

DEM (Discrete Element Method)?

- 모양이나 크기가 다른 다양한 입자의 움직임을 파악하기 위한 해석 방법

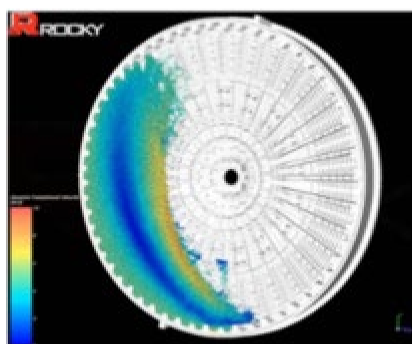
- 원자재 이송(광업)
- 활송 장치 (Chute)
- 롤러, 진동 스크린 스크린
- 컨베이어 이송 장치
- 분쇄기
- 각종 원자재 이송

Crusher

- 제철
- 마쇄기 (Mill)
- 노 (Furnace)
- 분말 야금

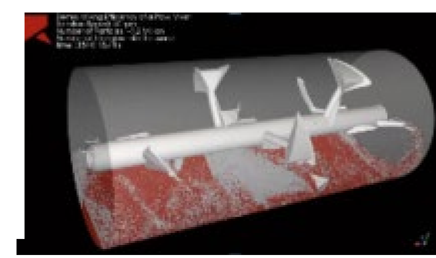
Excavator

- 중공업
- 중장비
- 자재 이송 등



Mill

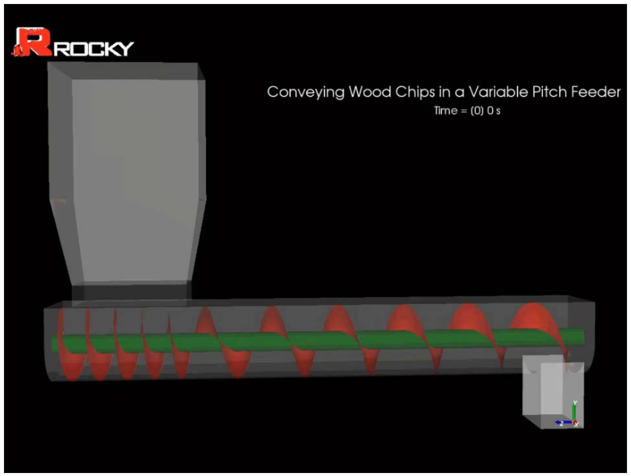
- 화학 및 제약
- 혼합
- 유동상 반응기 (Fluidized bed)
- 알약 코팅



Plow Mixing

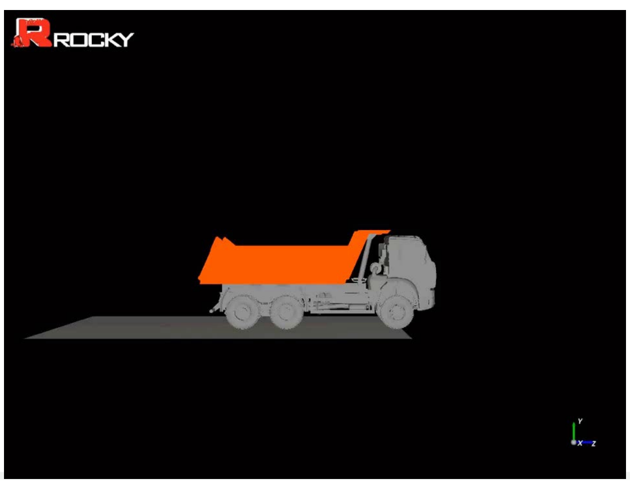
DEM ?

원자재 이송

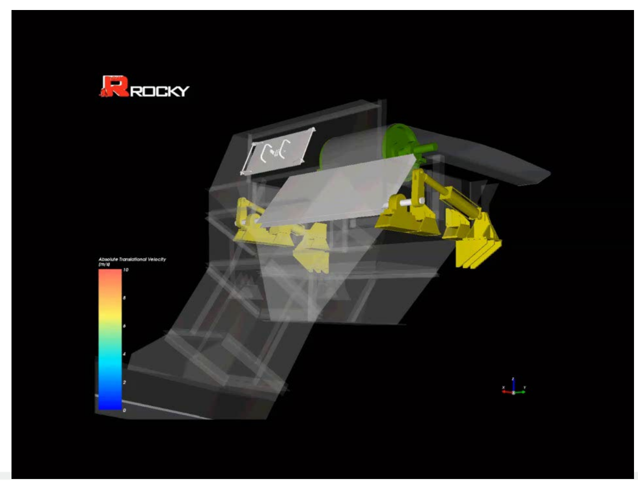


알약 코팅

덤프 트럭

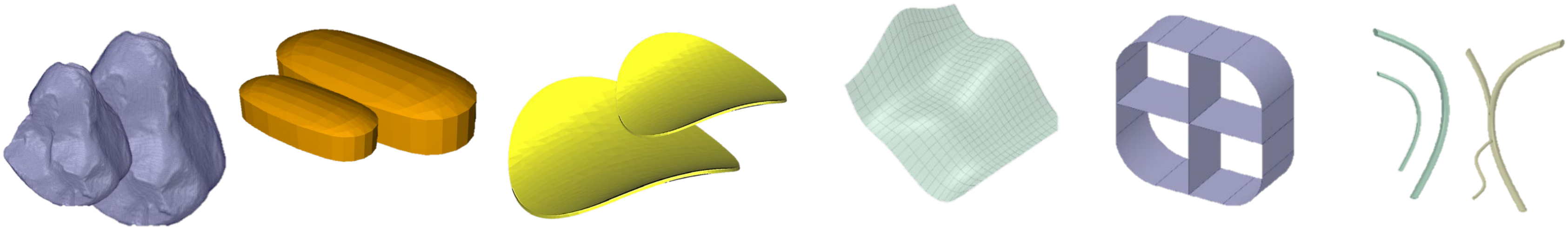


젖어 있거나 끈적끈적한 광물의 이송



OUTLINE: WHY IS ROCKY UNIQUE?

- 정확성



- 해석 속도

Windows 10

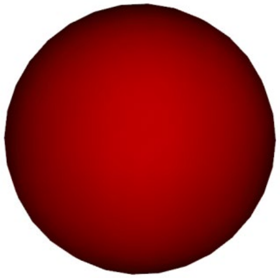
Powered By Linux

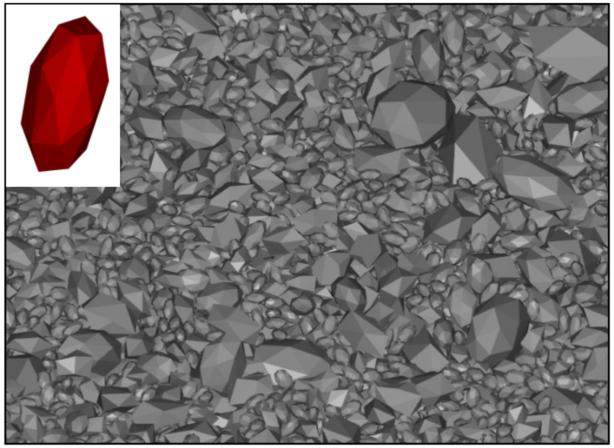
First Ever Multi-GPU Solver for DEM!

- 다양한 후처리 기능
- 사용 편의성
- ANSYS Mechanical (Static & Transient) 및 Fluent와의 완벽한 호환성

2. 정확성

WHY REAL SHAPE MODEL?

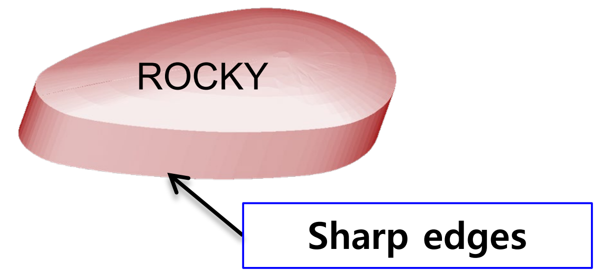




	Sphere type	Real Shape
지원 S/W	경쟁 프로그램 & ROCKY	ROCKY
마찰력	접촉 면적이 작기 때문에 작게 계산된	실제 형상 구현으로 정확한 마찰력 고려
Rolling Resistance	둥근 형태로 구름에 대한 구름저항(Rolling Resistance)이 거의 없음	실제 형상 구현으로 정확한 구름저항(Rolling Resistance) 구현 가능
정확도	정확도가 떨어짐, 운동성능이 과하게 계산 됨	매우 정확함
입자 파손	구현 불가능	입자 파손 모델을 이용해 현실적인 파손 구현 (각기 다른 모양과 크기로 파손됨)

WHY REAL SHAPE MODEL?

▶ **Sphere type의 약점 보안을 위한 타사 프로그램의 real shape particle**



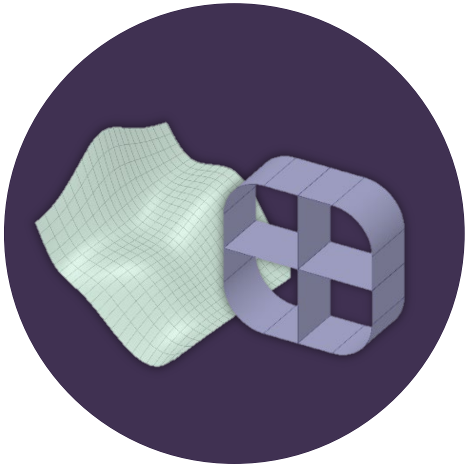
	타사 프로그램	ROCKY
입자 구현	- Sphere type의 particle을 접합하여 형상 구현 - 형상을 구현하기 위한 M/H 소모가 많음	- 몇 개의 parameter 조절을 통해 다양한 형태의 형상 구현 가능 - CAD 파일을 통해 구현 가능
입자 특징	높은 종횡비, 날카로운 모서리 구현 불가능	높은 종횡비, 날카로운 모서리 구현 가능
마찰력	울퉁불퉁한 형상은 큰 마찰이 발생함	실제 형상 구현으로 정확한 마찰이 발생함
정확도	정확도가 떨어짐	매우 정확함
입자 파손	입자 형상을 구현한 결합 된 구형 입자의 접착력을 깨는 방식으로 파손 구현 (구성한 구형입자의 크기로 파손됨)	입자 파손 모델을 이용해 현실적인 파손 구현 (각기 다른 모양과 크기로 파손됨)
확장성	이종의 구조해석 및 CFD 해석 프로그램과 연성해석이 어려움	ANSYS Mechanical(Static & Transient) 및 FLUENT와의 완벽한 호환

PARTICLE SHAPES IN ROCKY 4.1

- 다양한 종류의 입자로 해석 가능

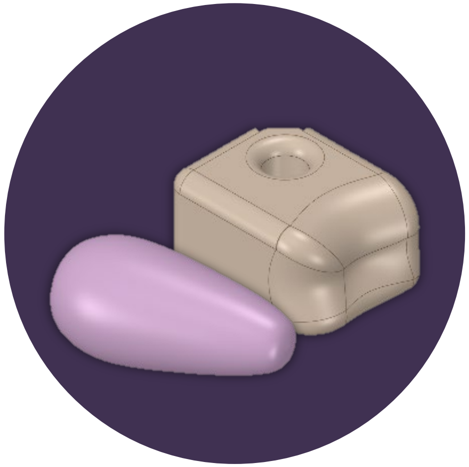
FIBER

- ✔ Flexible
- 🕒 Breakage



SHELL

- ✔ Flexible
- 🕒 Breakage

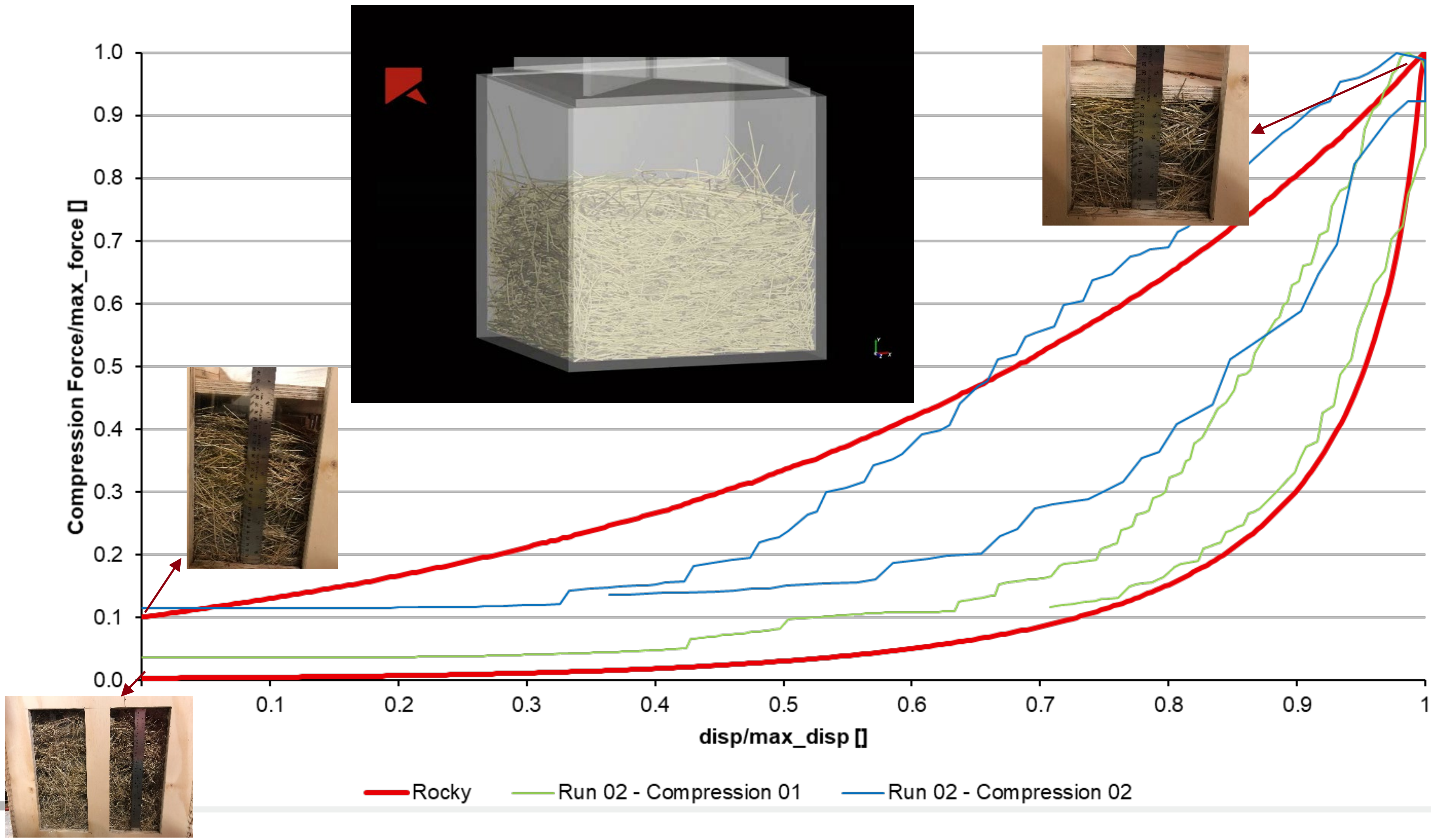


SOLID

- ✔ Flexible
- ✔ Breakage

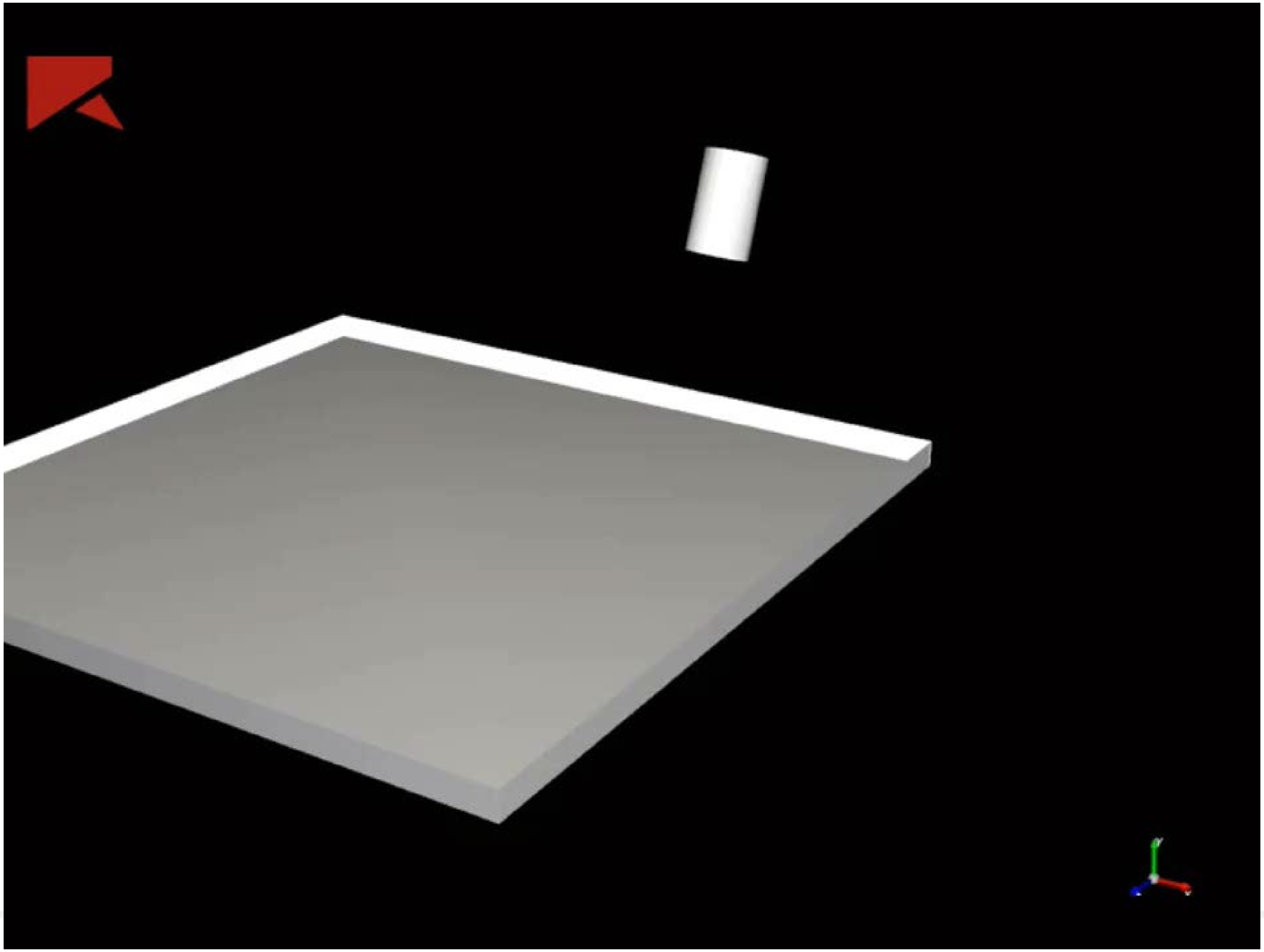
FLEXIBLE FIBER: ACCURATE STRESS-STRAIN RESPONSE

- 실제 형상(Flexible Fiber)을 반영한 입자를 사용하여 해석 수행



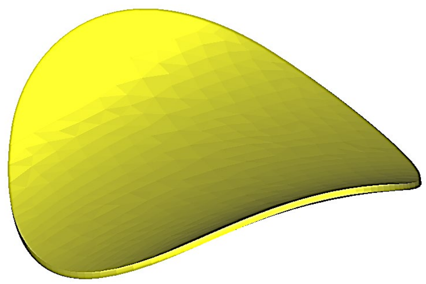
FLEXIBLE FIBERS WITH CFD COUPLING

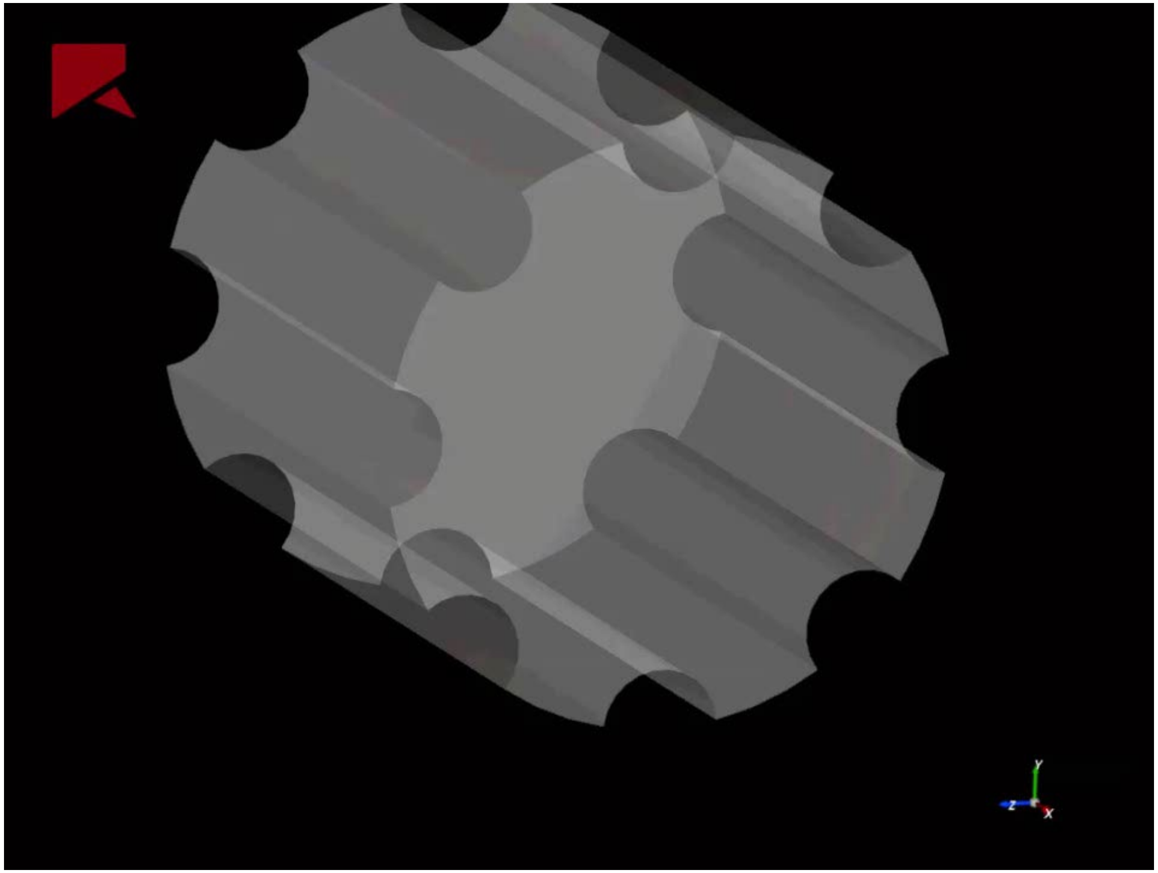
- 실제 형상(Flexible Fiber) 및 주변 유동 흐름을 반영한 해석 수행



UNIQUE FEATURES OF ROCKY: PARTICLE SHAPES

- 강체 쉘 (Rigid Shell)
  - 감자 칩 형태를 그대로 반영하여 해석 수행

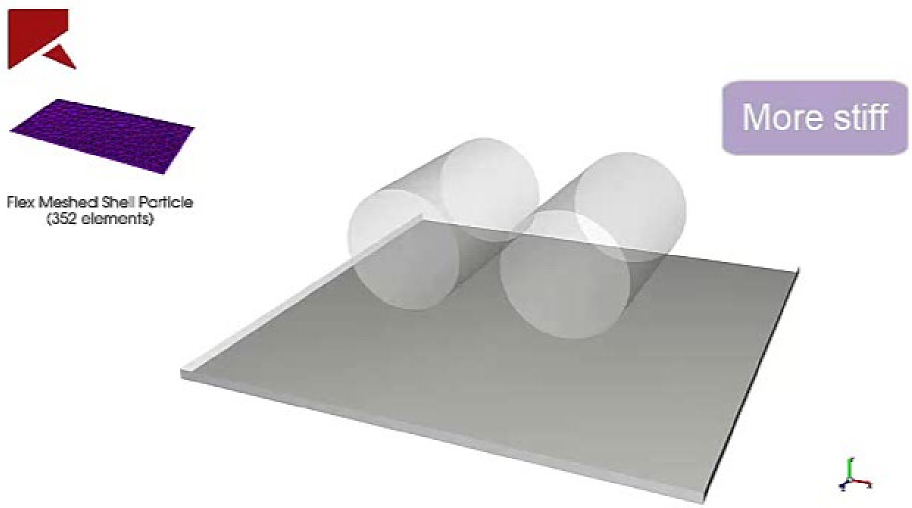


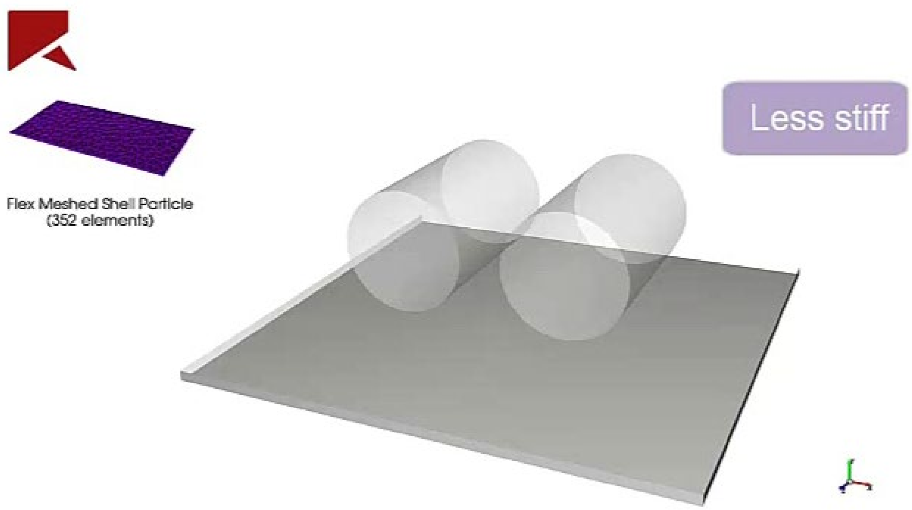


감자 칩 로스팅

UNIQUE FEATURES OF ROCKY: PARTICLE SHAPES

- 탄성체 쉘 (Rigid Shell)
  - 입자의 딱딱한 정도(Stiffness)에 따른 거동 분석



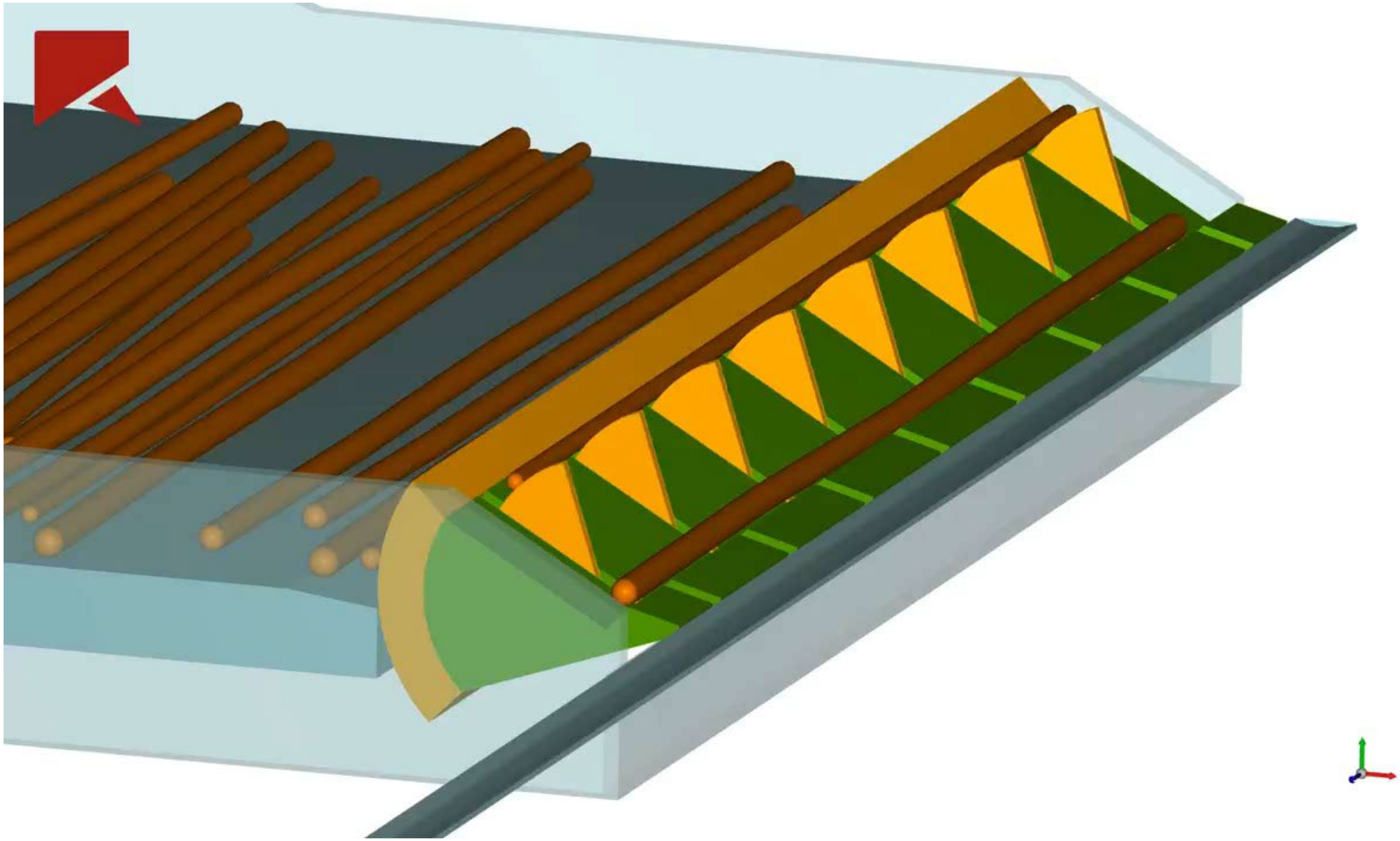


UNIQUE FEATURES OF ROCKY: PARTICLE SHAPES

- 사용자 정의 3차원 입자(Solid)

UNIQUE FEATURES OF ROCKY: PARTICLE SHAPES

- 사용자 정의 3차원 입자(Solid)



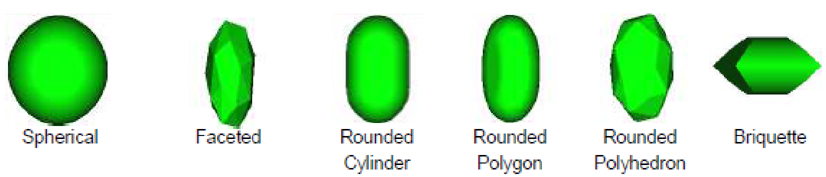
EMBEDED PARTICLE SHAPES

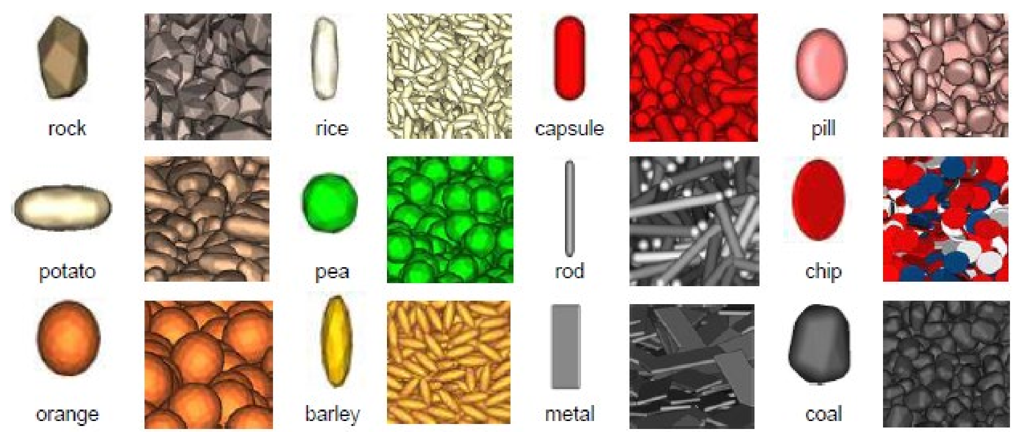
ROCKY에서 기본적으로 제공하는 입자 형태

Unequalled Depth

ROCKY는 현실적인 입자 모양을 구현함으로써 해석의 정확도를 향상시킴

기본 입자 형상



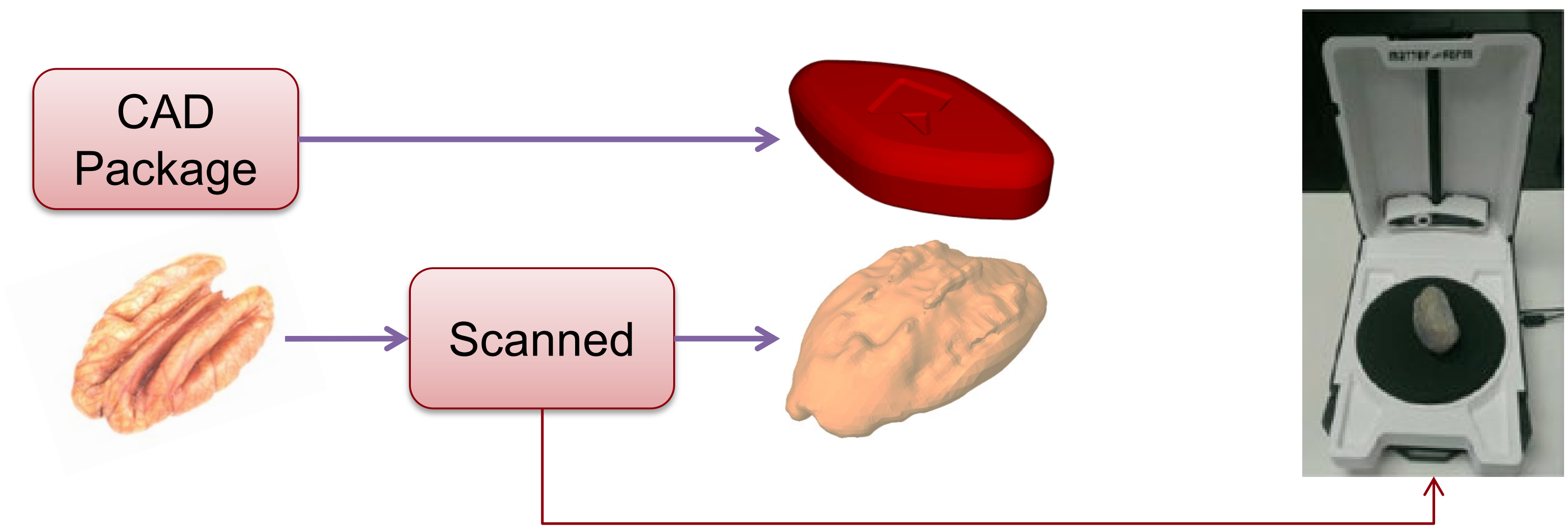


PARTICLE CUSTOM SHAPES

사용자 정의 입자 모양 구현

Unequalled Depth

CAD 파일 및 3D 스캐너를 이용하여 입자 모양 구현 가능

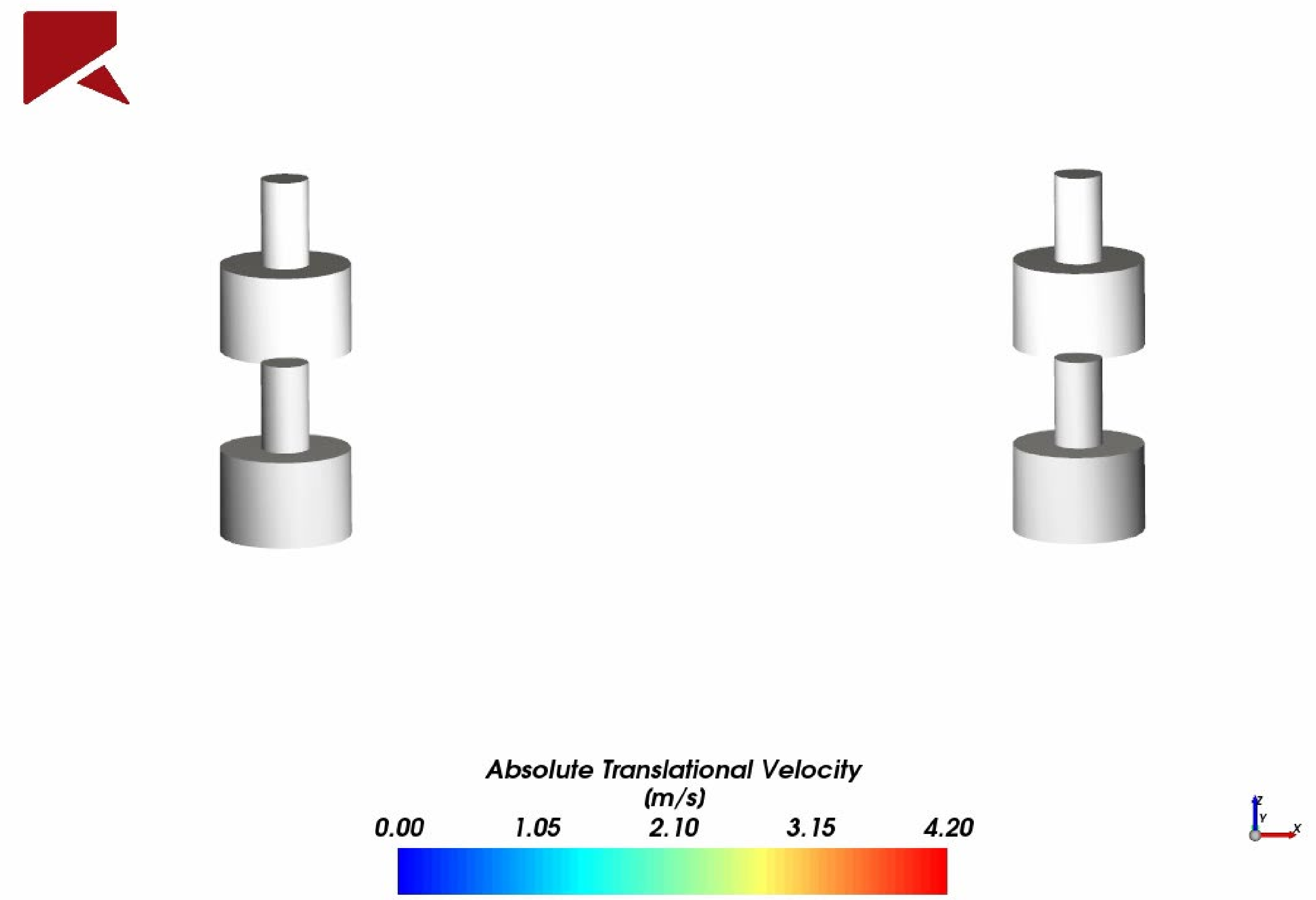


COMBINING FIBERS, SHEELS AND SOLIDS

- 1차원(Fiber), 2차원 (Shell), 3차원 (Solid)입자를 혼합한 해석

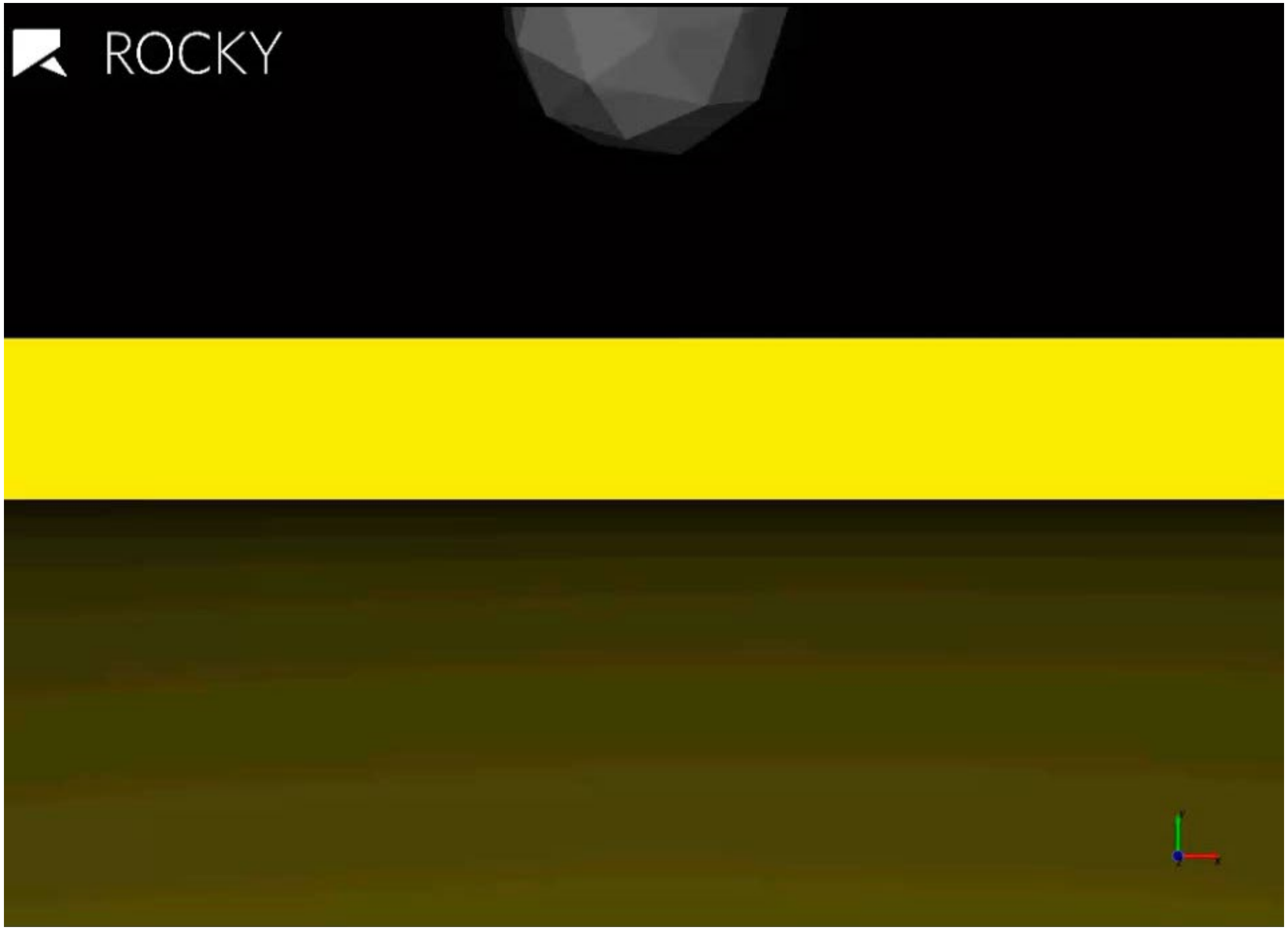
COMBINING FLEXIBLE & RIGID

- 유연체(Flexible) 입자와 강체(Rigid) 입자를 혼합한 해석



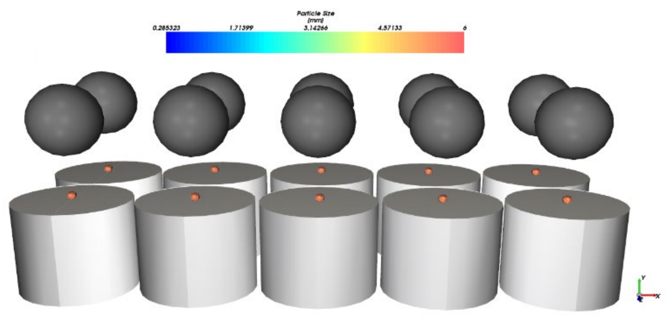
ACCURATE, WITH REAL PHYSICAL REPRESENTATION

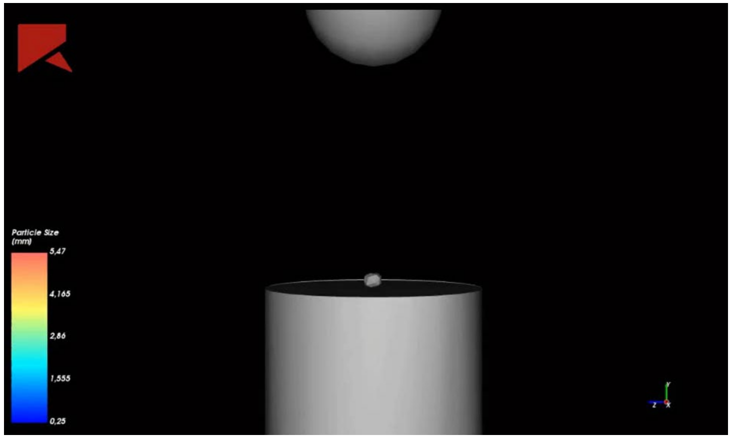
- 입자 파손 (Particle Breakage)



TAVARES BREAKAGE MODEL

- Drop Weight Test 결과 검증:
  - 광산업에서 광물의 특성을 파악하기 위해 수행하는 모델 테스트와의 결과 검증
  - 강도가 다른 구리광석과 석회석에 대하여 결과 검증 수행 (직경 5.41mm)



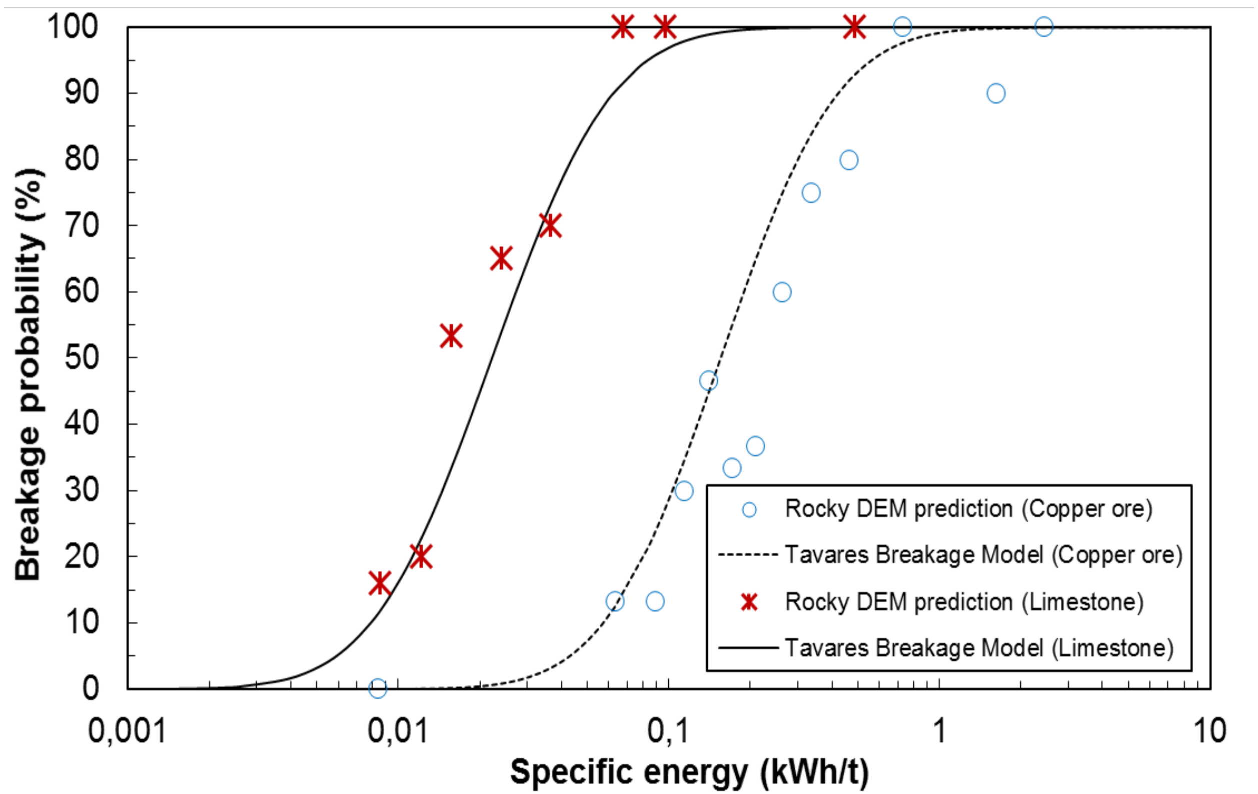


> *The Tavares model in Rocky DEM allows more-realistic simulations of systems in which particle breakage occurs, by consistently describing size-dependent breakage probability, fragment distribution, and weakening by damage accumulation. In particular, the model is very useful in describing ore degradation during handling as well as size reduction in different types of crushers, providing greater confidence in predicting both the proportion of broken particles and product size."*

Professor Luis Marcelo Tavares

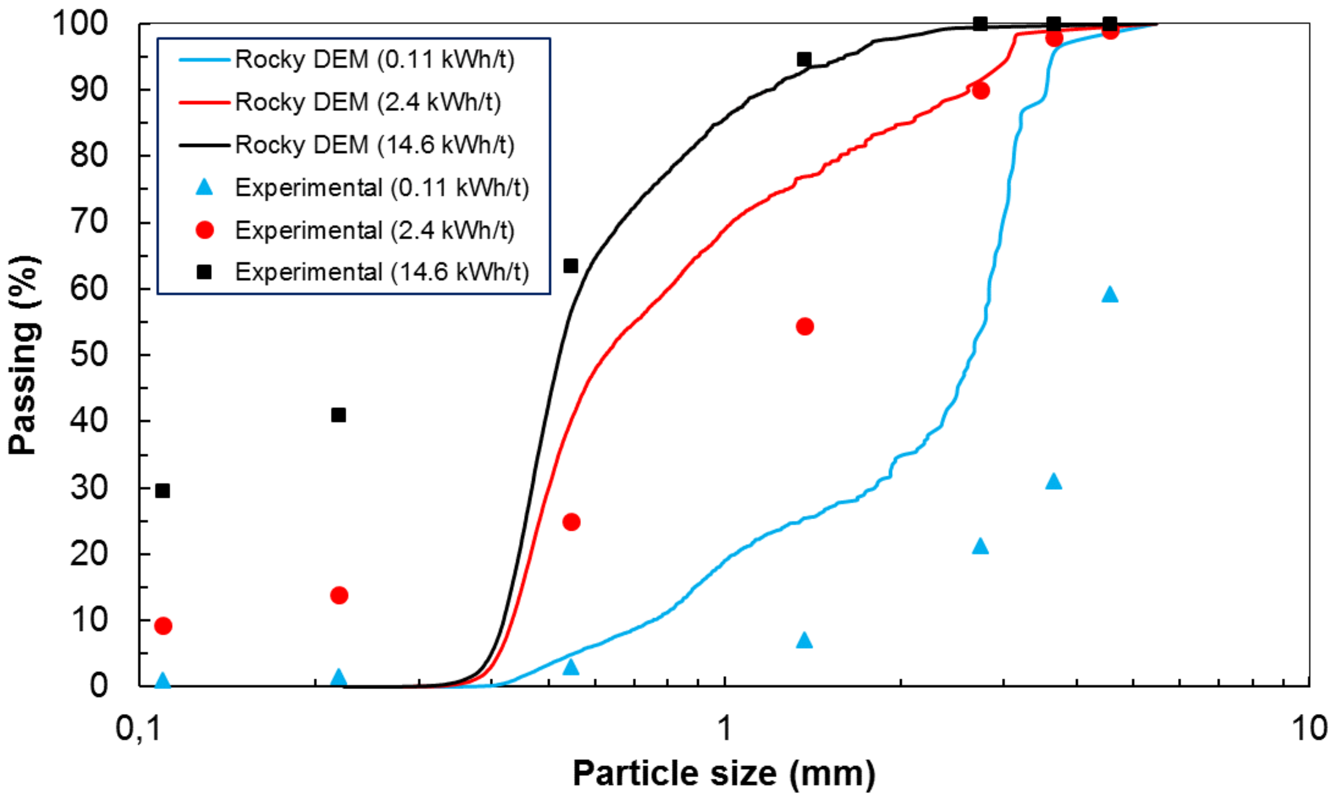
TAVARES BREAKAGE MODEL 검증

- 입자 파손 확률:
  - 재료 특성에 따라 파손 확률 검증
  - ROCKY 해석 결과는 Tavares Breakage Model과 높은 결과 일치 도를 보임



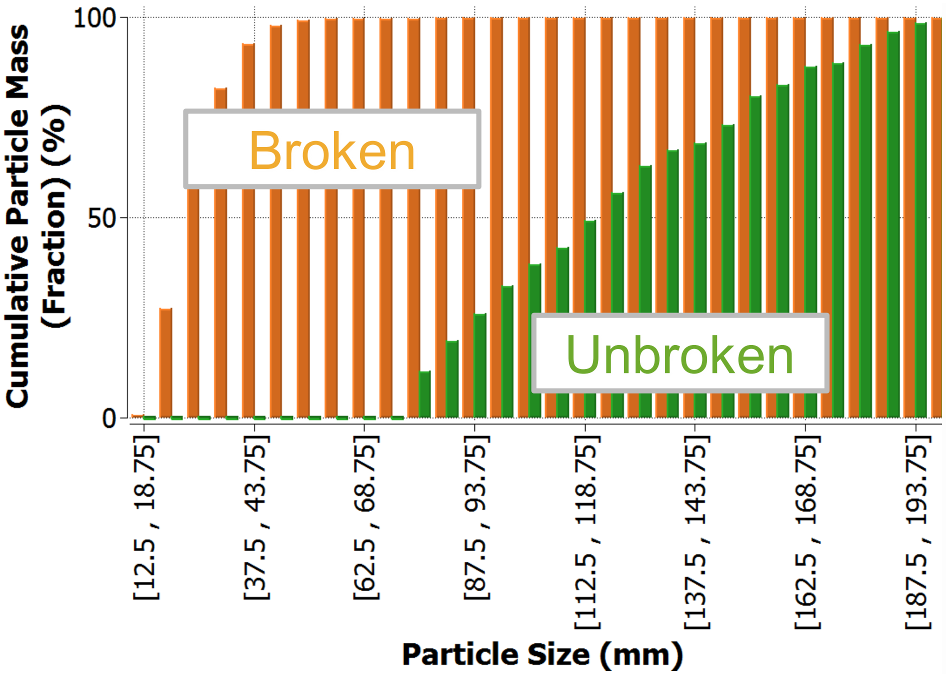
TAVARES BREAKAGE MODEL 검증

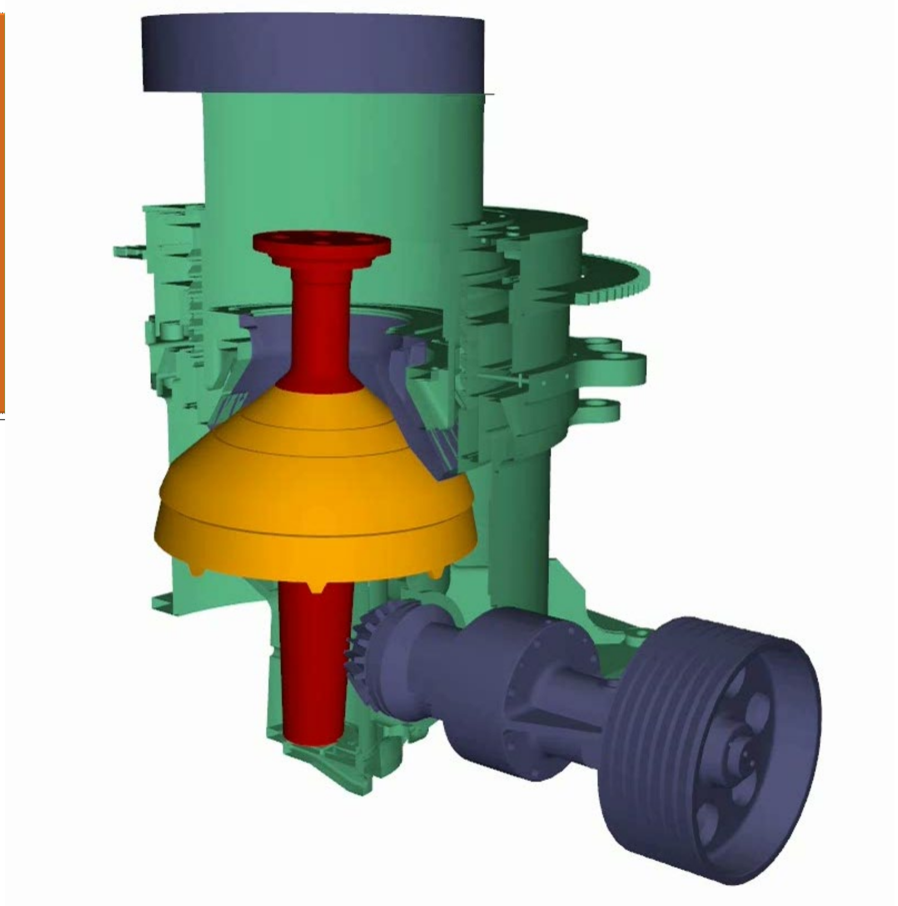
- 입자 파손 후 파편 분포:
  - 다양한 충돌에너지에서 파편의 크기 분포 분석
  - 높은 충돌에너지에서 파편이 잘게 파쇄됨
  - 입자 파손이 크게 일어나는 높은 충돌에너지에서 실험과 해석결과의 일치 정도가 높음



ACCURATE, WITH REAL PHYSICAL REPRESENTATION

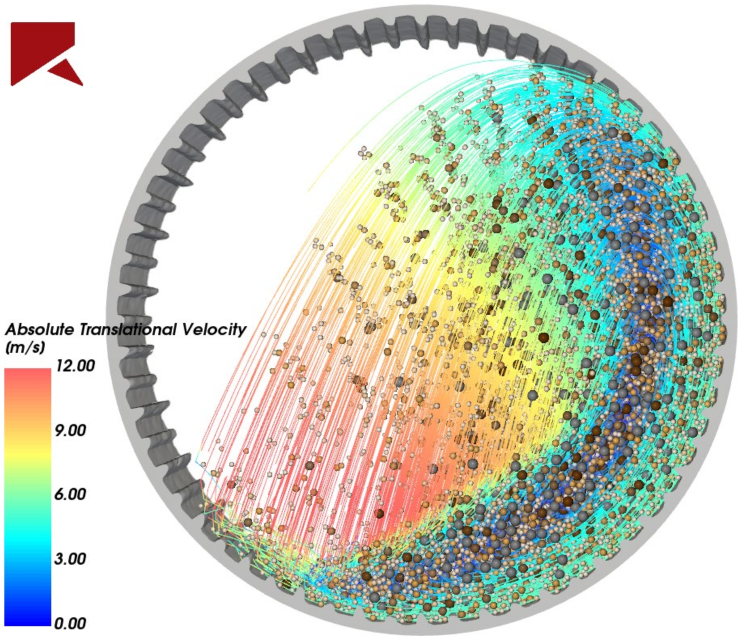
- 파손 입자 크기 분포에 대한 후처리

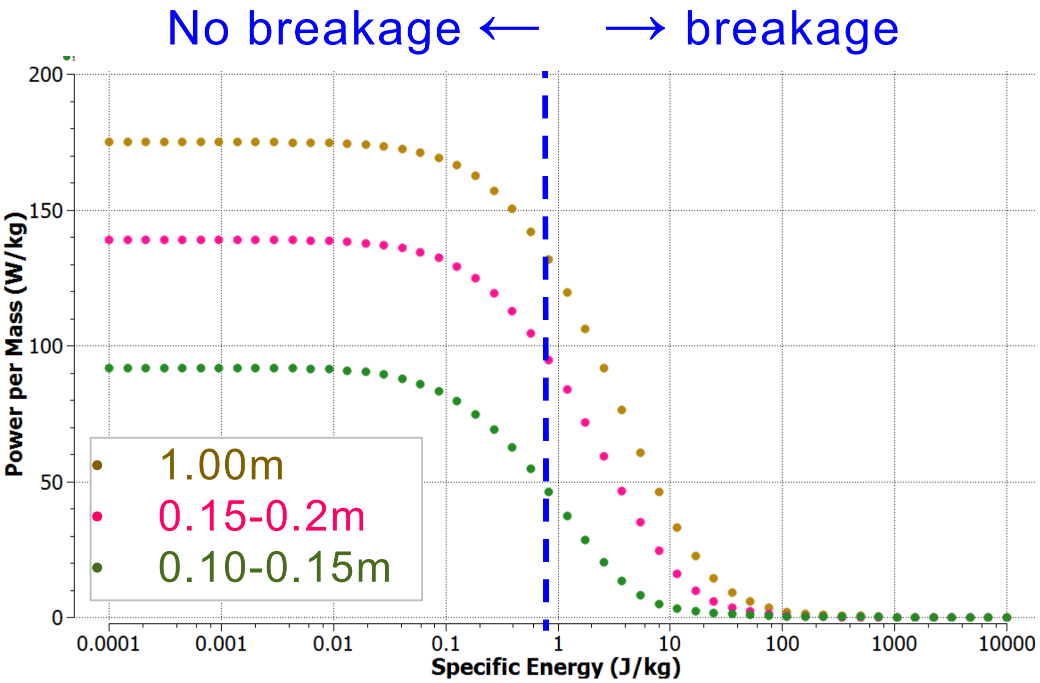




ACCURATE, WITH REAL PHYSICAL REPRESENTATION

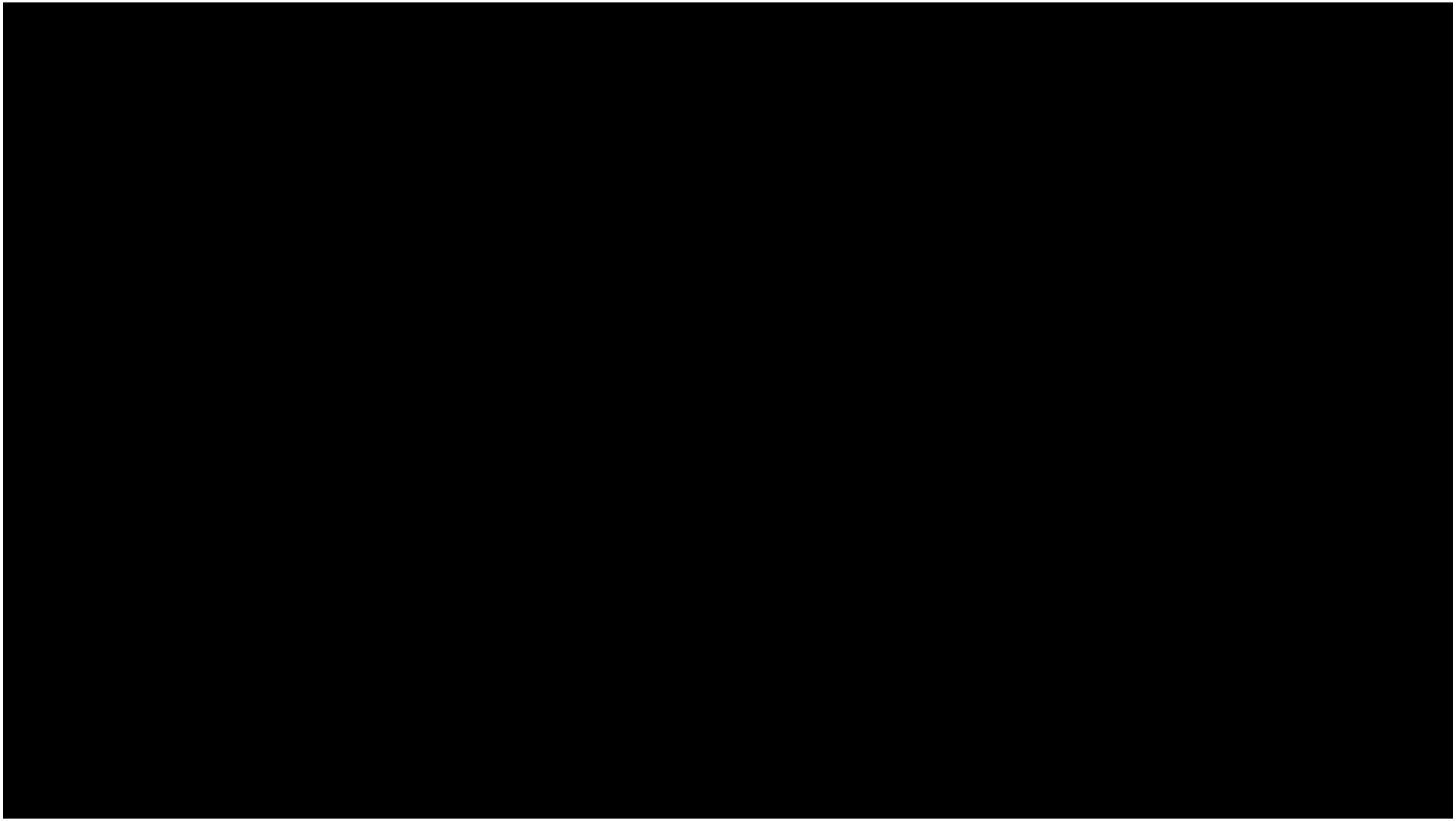
- 입자 에너지 스펙트럼 (Particle Energy Spectra)
  - 단위 시간당 개별 입자에 적용되는 충격 에너지 통계 값을 기반으로 파손 여부 평가 가능





ACCURATE, WITH REAL PHYSICAL REPRESENTATION

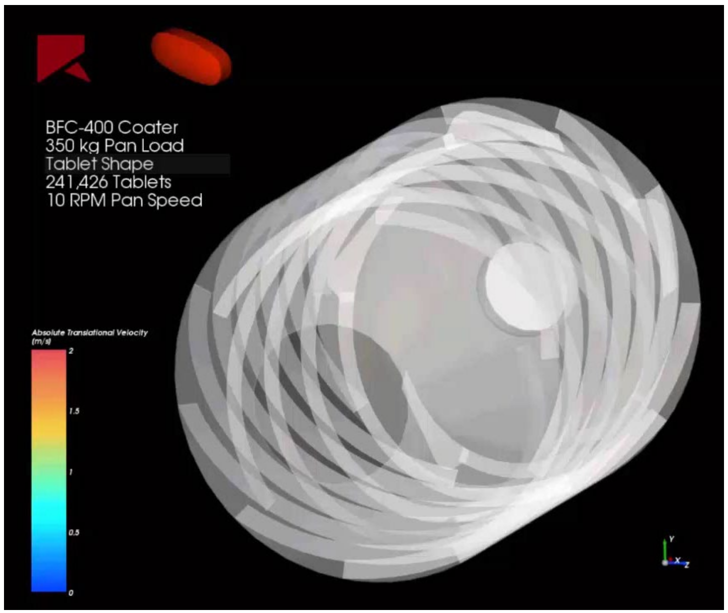
- 열전달 해석 (백만 개의 입자로 해석 수행)

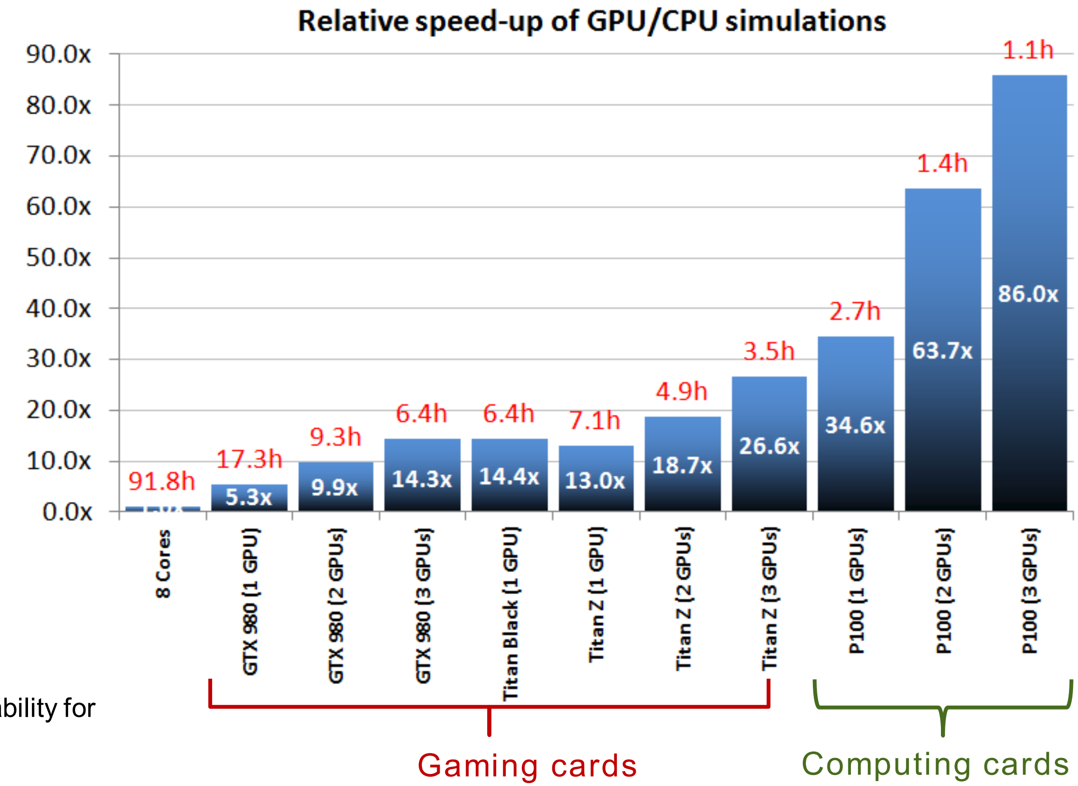


3. 해석 속도

FAST, HAVING AND UNPRECEDENTED PERFORMANCE

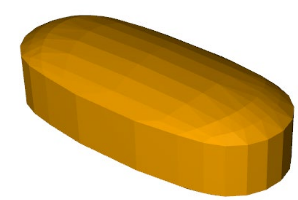
- GPU 및 CPU를 활용한 병렬 계산





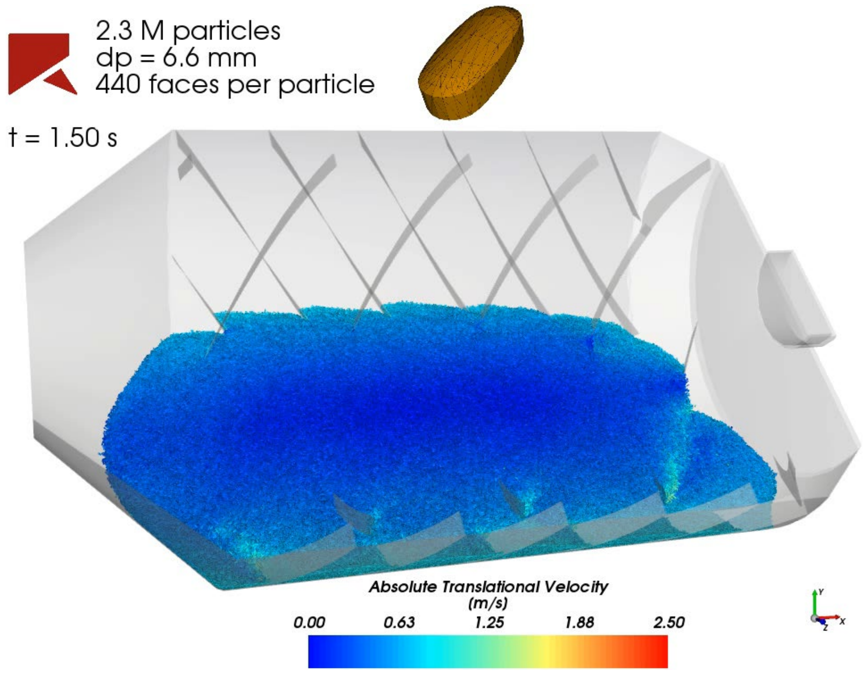
Advances in DEM Computing Which Improve Predictive Capability for Processes, AIChE 2016, Stomata *et al.*

- 실제 상업용 크기의 알약 코팅기를 10 RPM으로 회전
- 222개의 노드를 갖는 242,000 개의 사용자 정의 입자 해석



IMPROVED PROCESS PERFORMANCE VIA MULTI GPU

- 실제 알약 형상 반영
- 10억 개 이상의 요소
- 4개의 NVIDIA P100 GPU 활용



4.1 Release

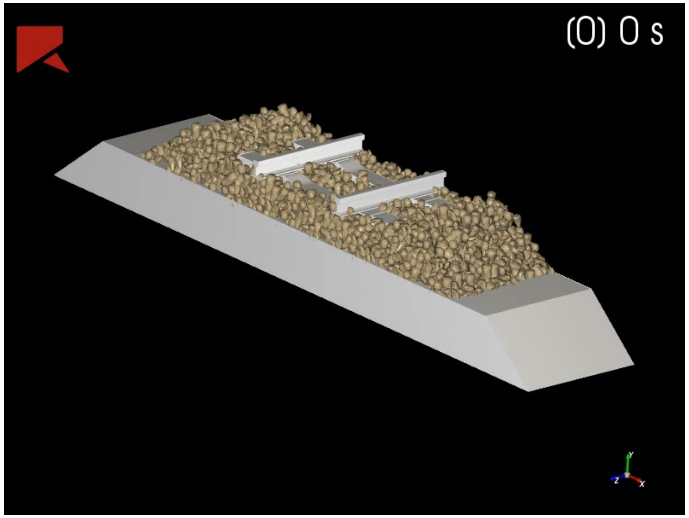
~10x
Faster

~10x
Less memory

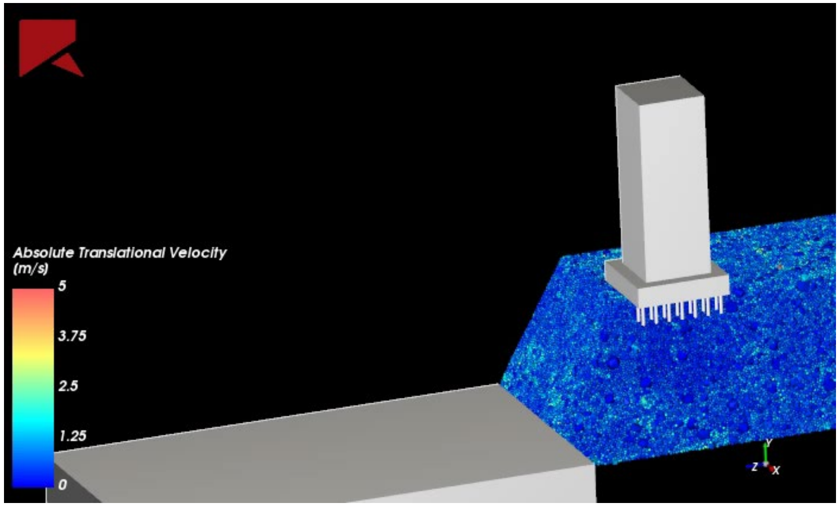
4. 다양한 후처리 기능과 사용 편의성

TAILORED FOR EQUIPMENT DESIGNERS

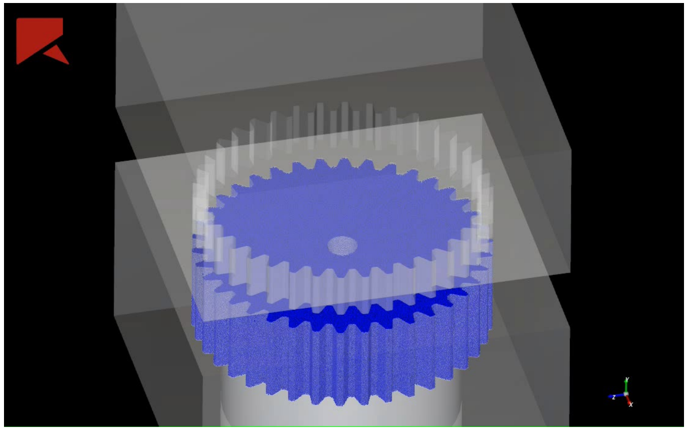
Ballasted Layer Deformation



Building in Landslide



Powder Compaction

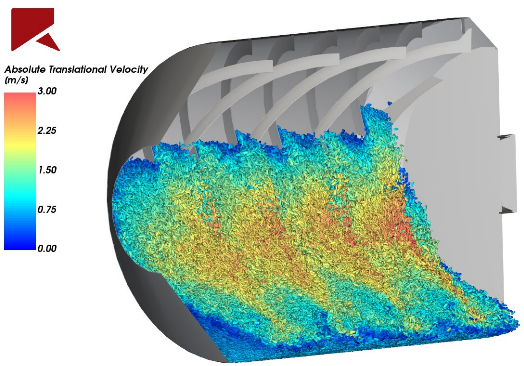


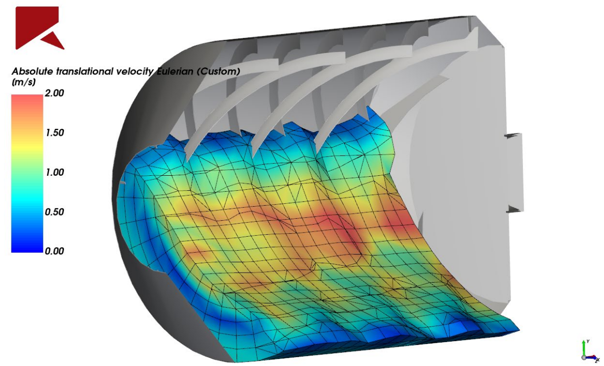
- 별도의 Multi-Body Dynamic S/W 필요 없이 다양한 모션 구현 가능
- 모든 구조는 Free Body로 모델링 가능 (입자에 의한 하중으로 모션 정의 가능)

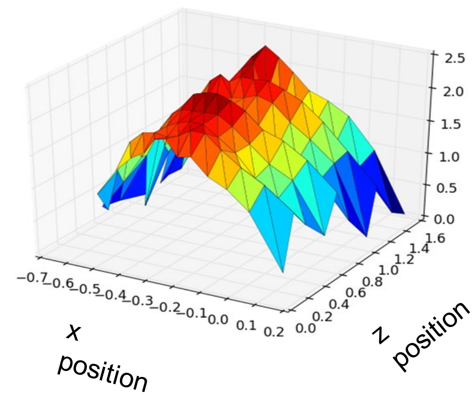
TAILORED FOR EQUIPMENT DESIGNERS

다양한 포스팅 방법

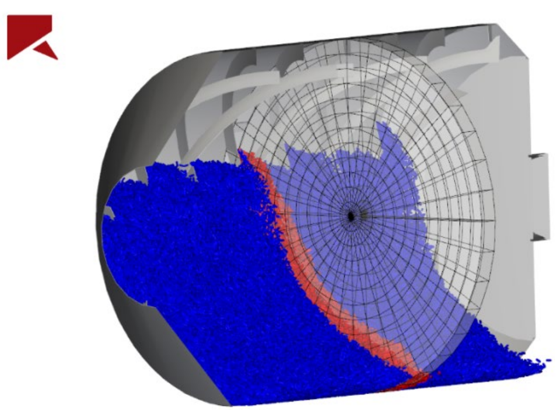
Velocity

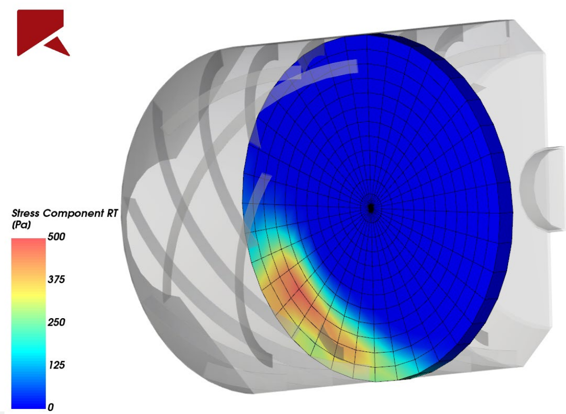


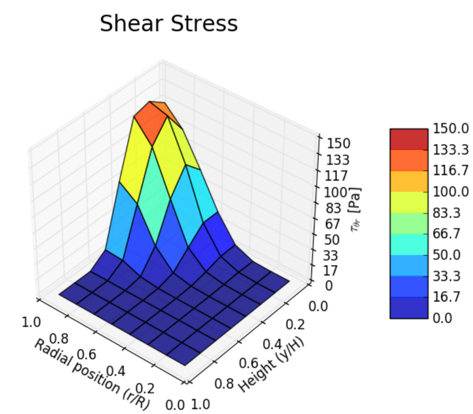




Stress



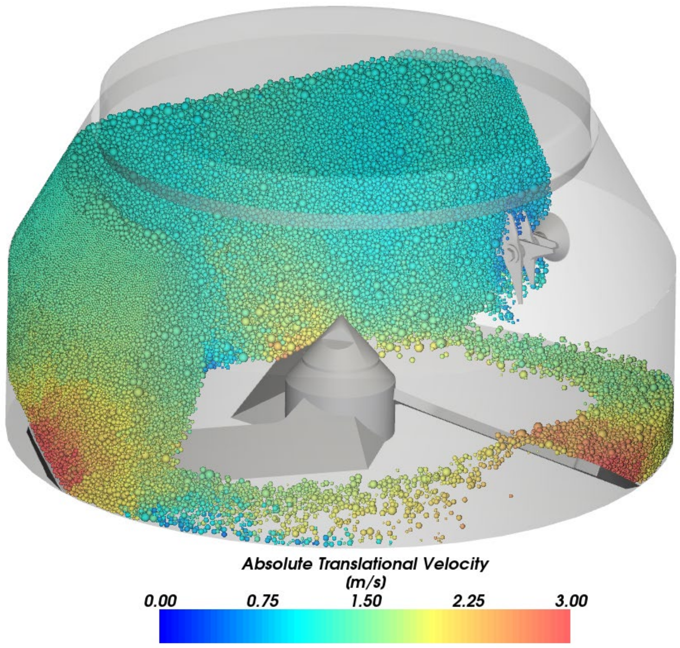




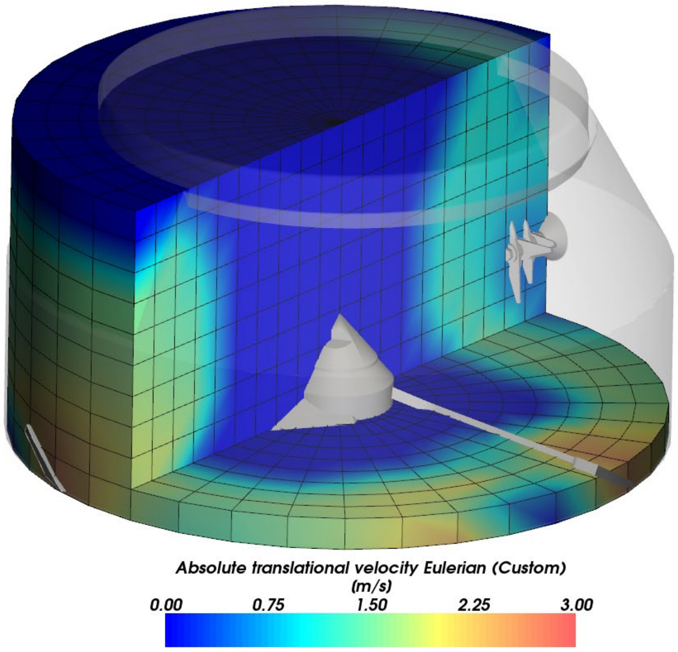
TAILORED FOR EQUIPMENT DESIGNERS

다양한 포스팅 방법

개별 입자의 해석 결과 포스팅



공간에 연속적으로 해석 결과 포스팅

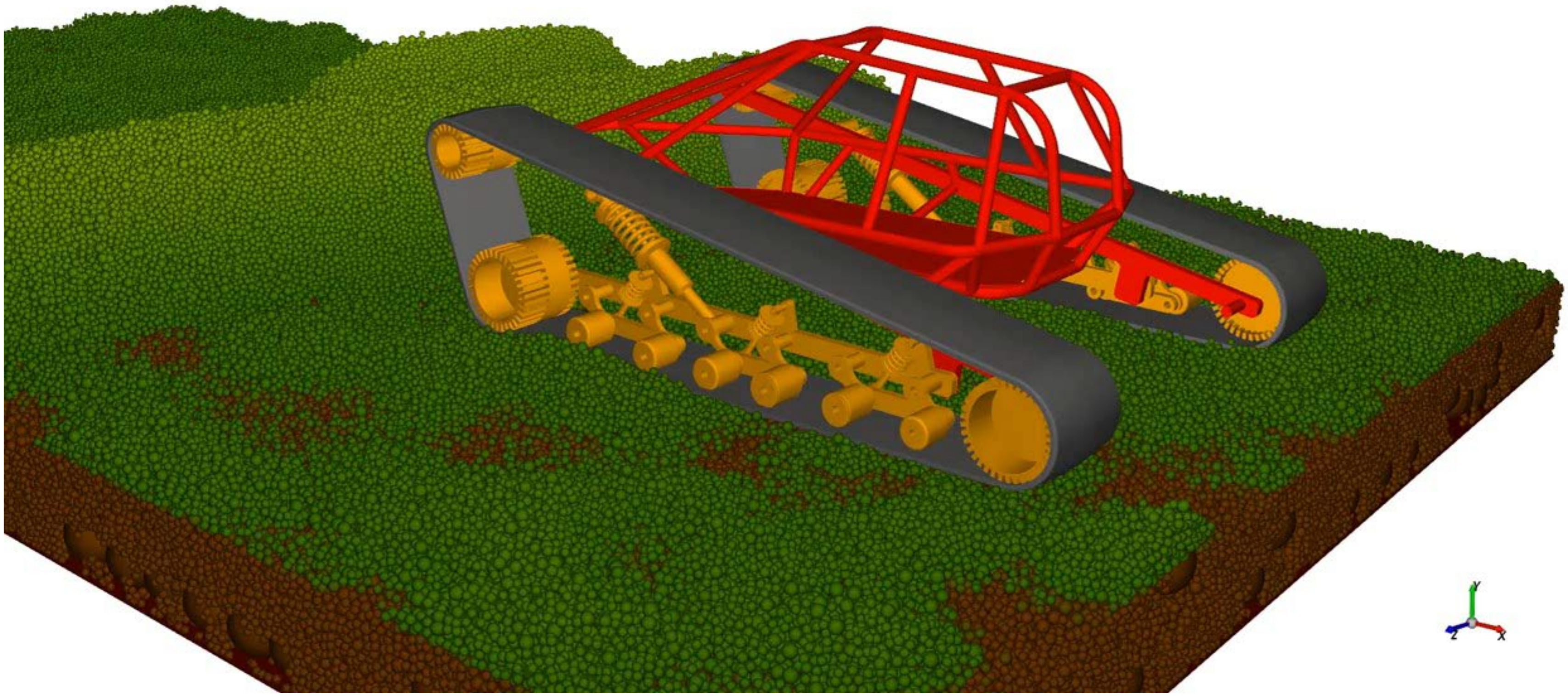


TAILORED FOR EQUIPMENT DESIGNERS

- 강력한 모션 구현 엔진

TAILORED FOR EQUIPMENT DESIGNERS

강력한 모션 구현 엔진



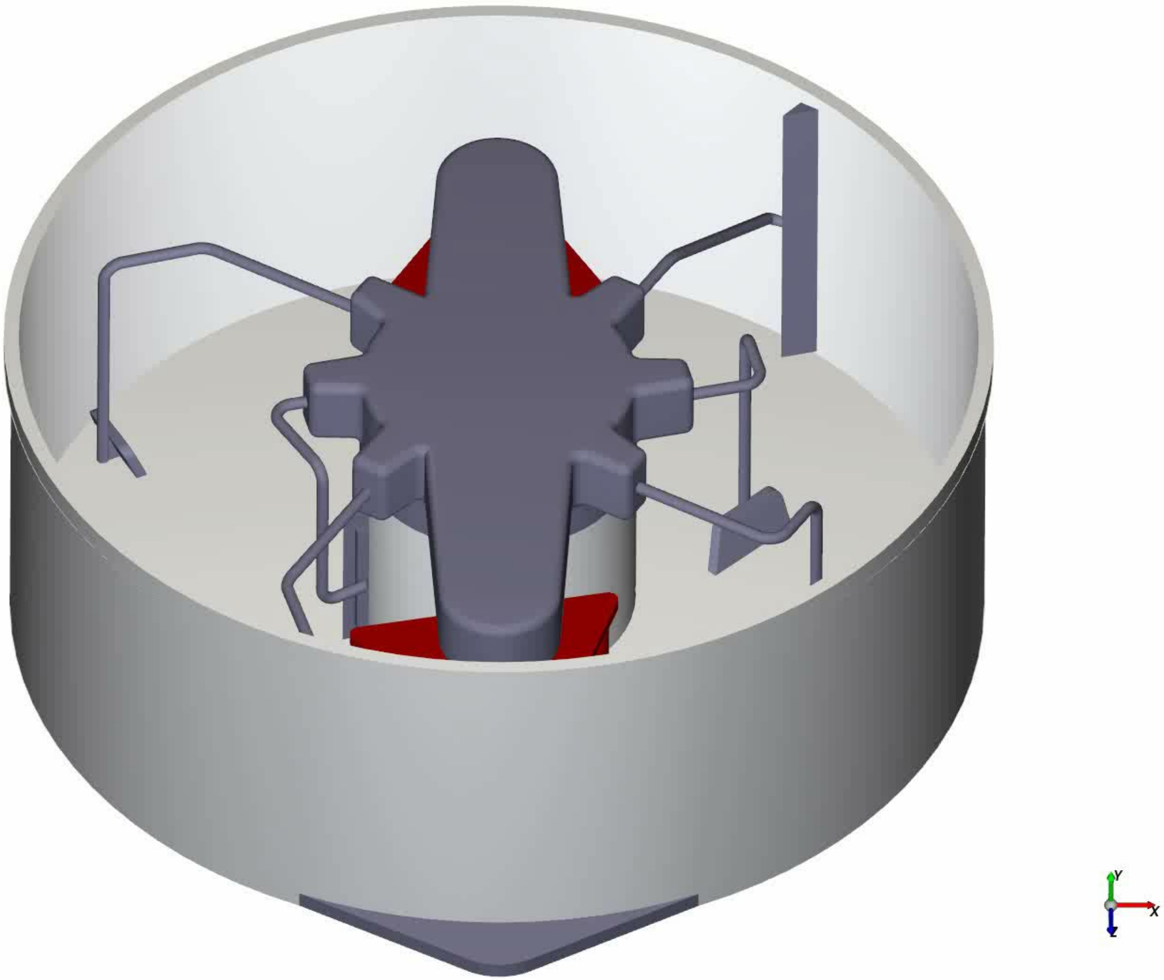
TAILORED FOR EQUIPMENT DESIGNERS

강력한 모션 구현 엔진

Demo of Multiple Moving Frames

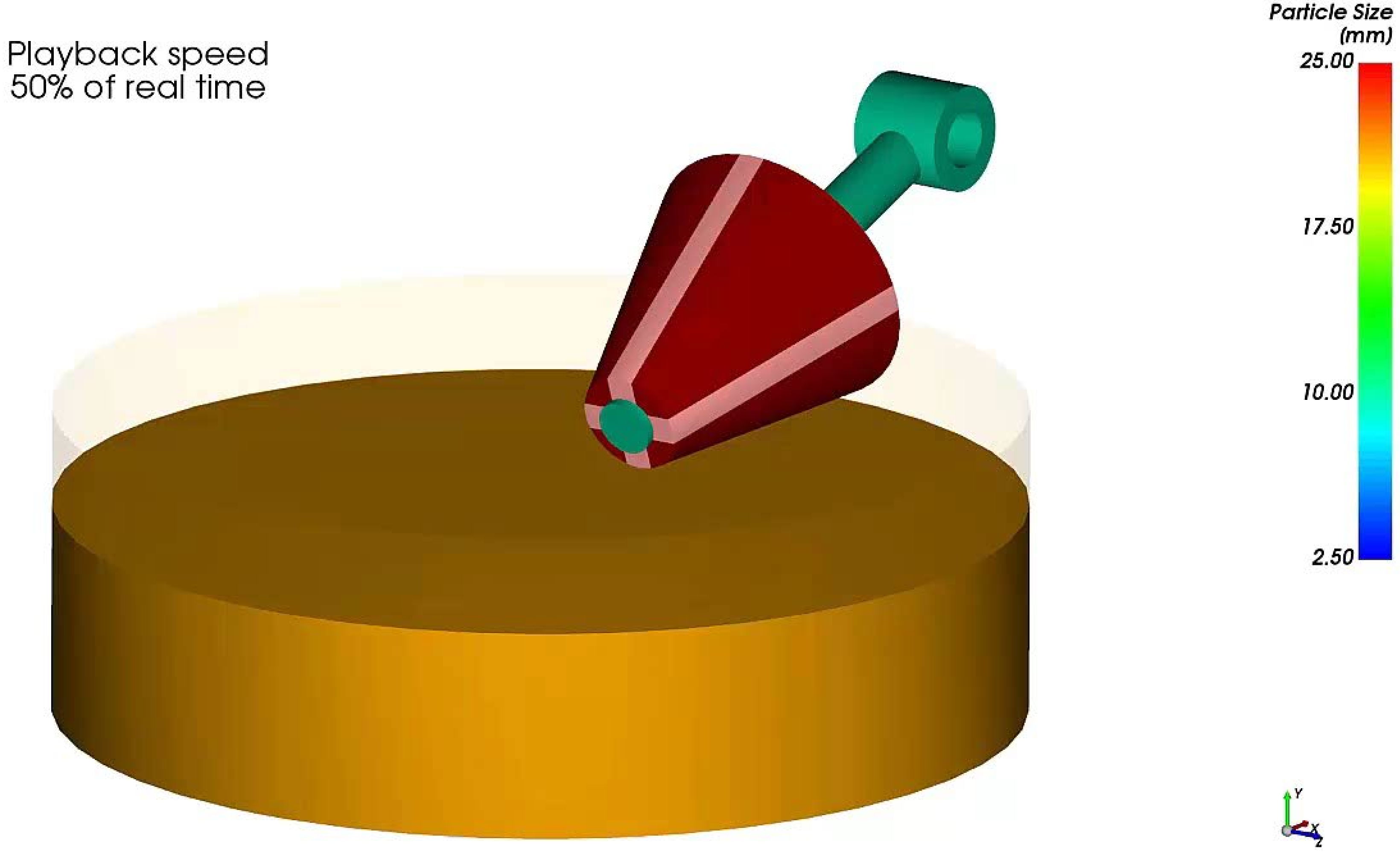
Geometry:
 Ring Pan Mixer
Diameter: 2.4 m
Arm rotation speed:
 16.4 rpm
Orbital 1 rotation speed:
 132 rpm
Orbital 2 rotation speed:
 184.8 rpm

Material
Wet cement:
Shape: Spherical
Diameter: 10 mm
 with Cohesion
Particle count: 1 million



TAILORED FOR EQUIPMENT DESIGNERS

- 강력한 모션 구현 엔진 + 실제 형상 구현 입자 & 입자 파손

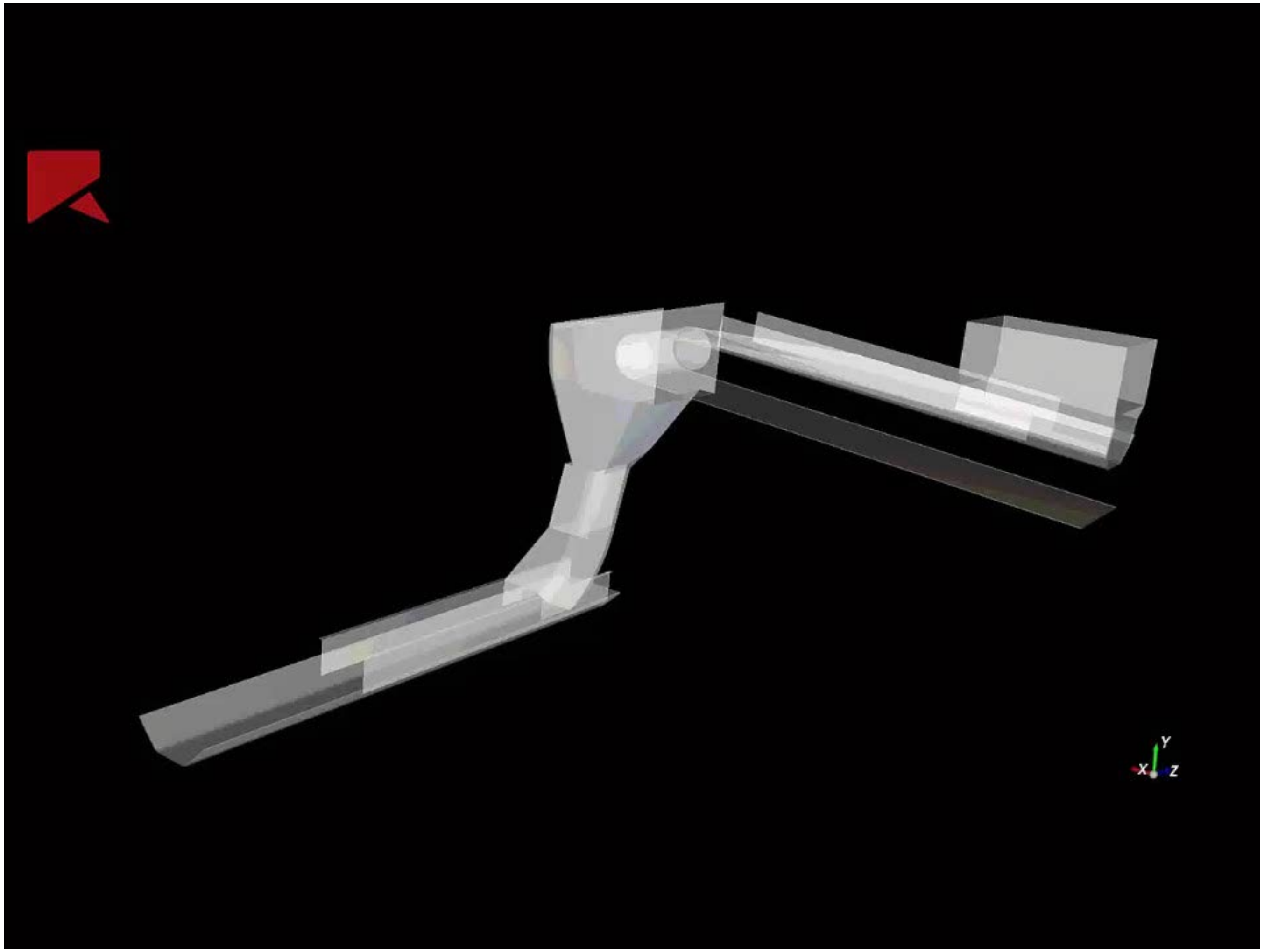


TAILORED FOR EQUIPMENT DESIGNERS

- 수분 및 끈적거림을 포함하고 있는 입자 해석

TAILORED FOR EQUIPMENT DESIGNERS

구조물 표면의 마모 평가



EXAMPLE: 혼합 성능 평가

블래이드(Blade) 형태 별 혼합 성능 평가

20 sec mixing at 90 rpm

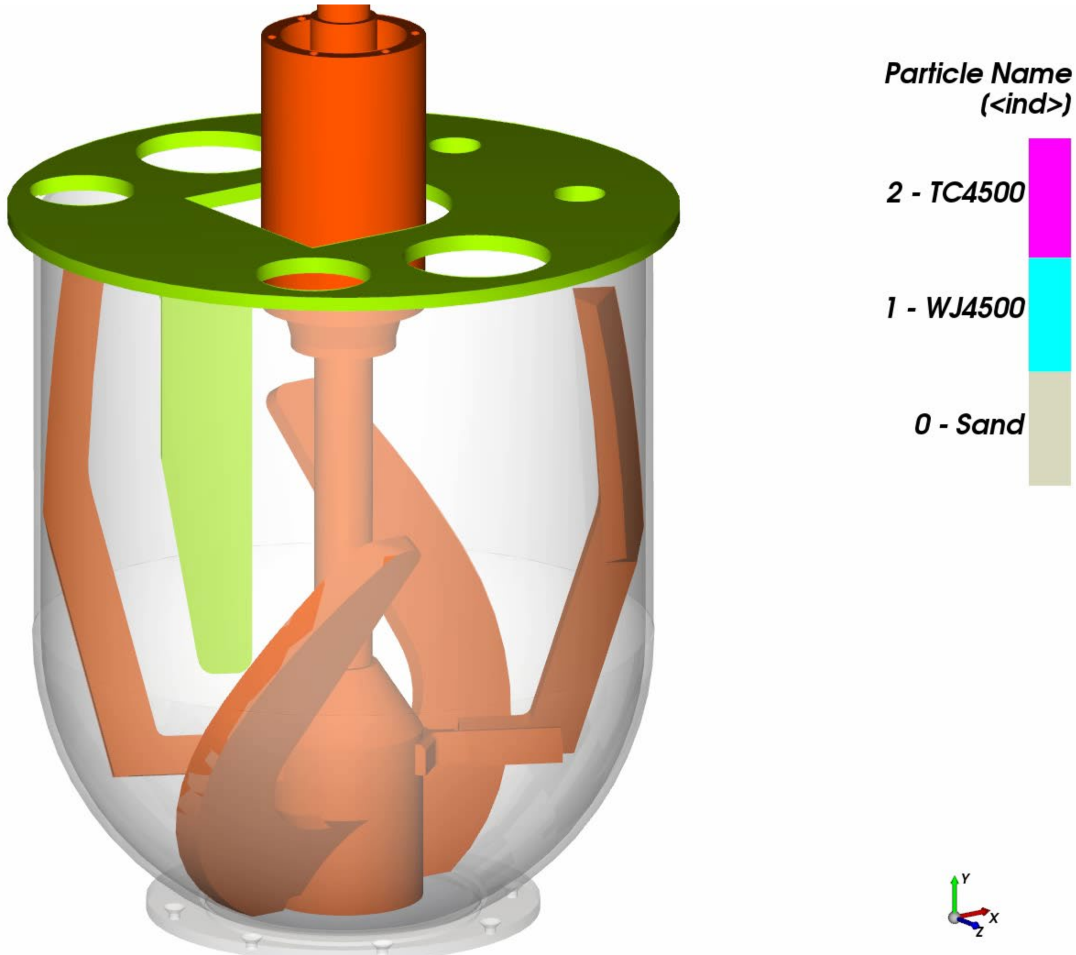
Sand - 60 kg

Additives (Sand mass %)
WJ4500 - 0.95%
TC4500 - 0.8%

Non rolling spheres

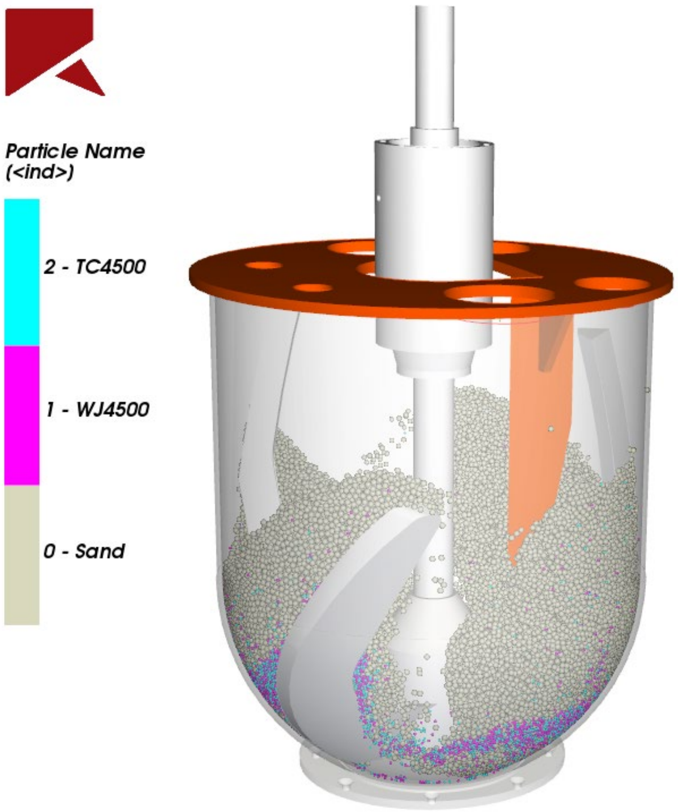
Playback speed 30% of real time

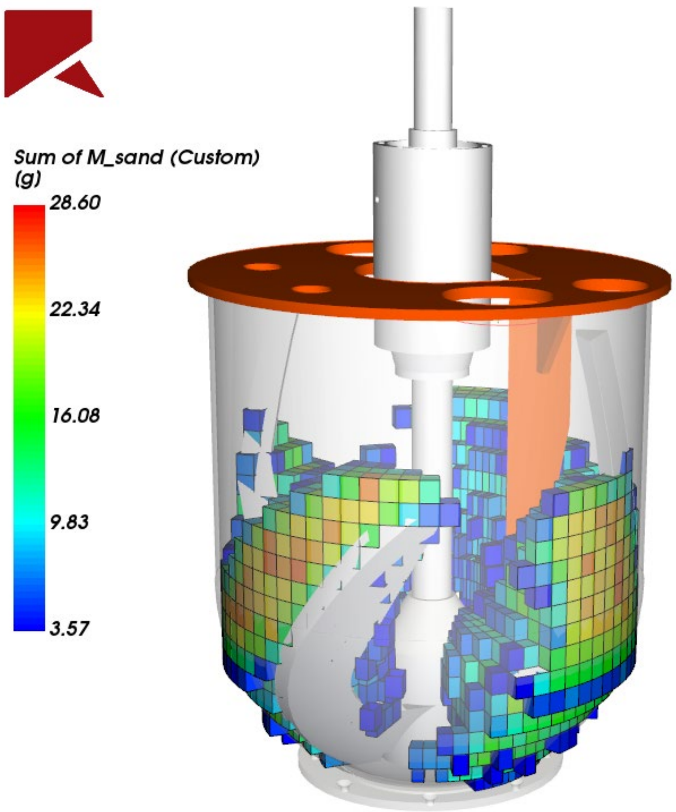
Simulation Time = 0.0000 s



EXAMPLE: 혼합 성능 평가

- 해석 영역을 여러 개의 영역으로 분할하여 결과 포스팅 가능
- 사용자 정의 식을 이용하여 결과 포스팅 가능

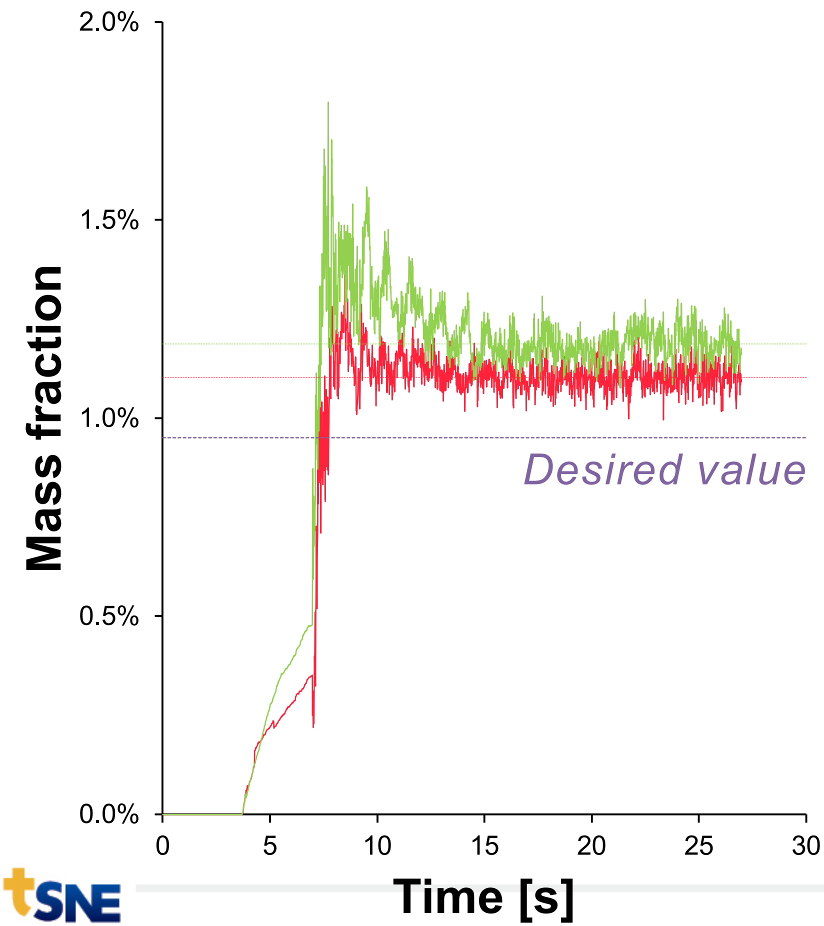




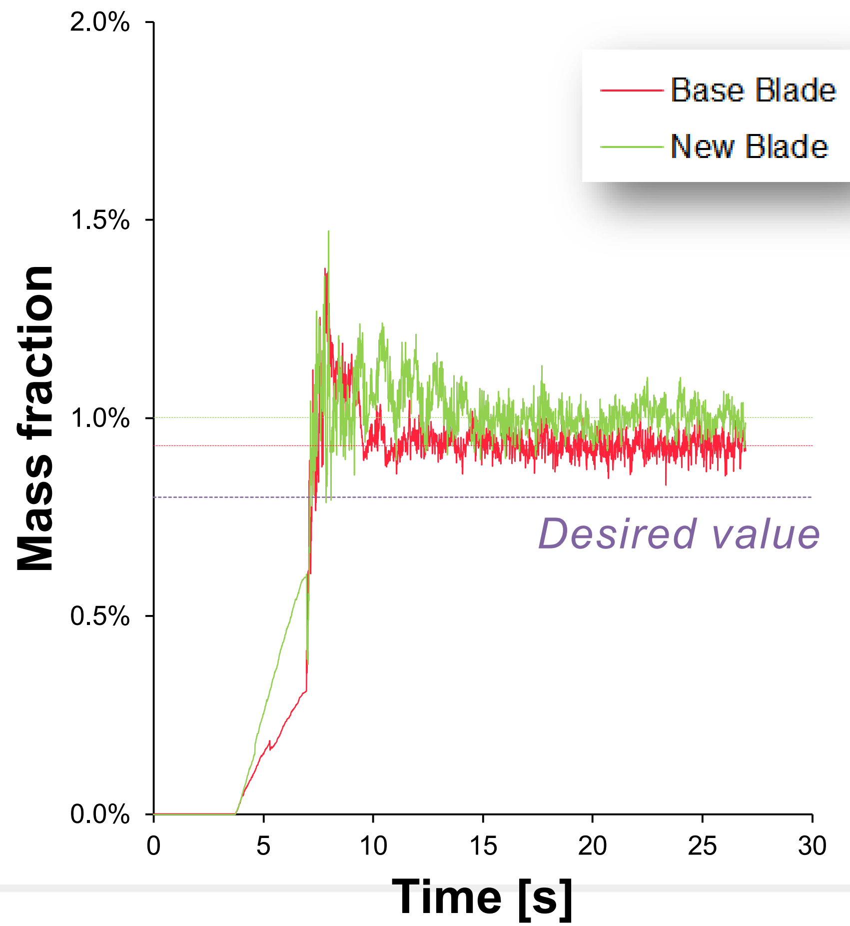
EXAMPLE: 혼합 성능 평가

- 시간 변화에 따른 질량 분율(Mass fraction) 평가
- 본 예시에서는 sand의 질량 분율 평균을 통해 blade의 혼합 효율 평가

WJ4500

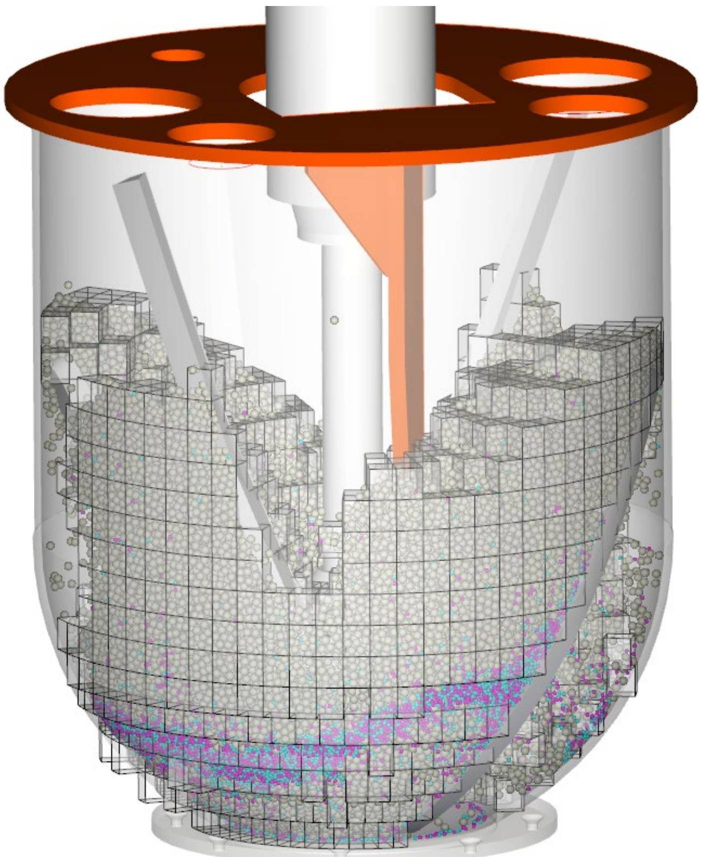


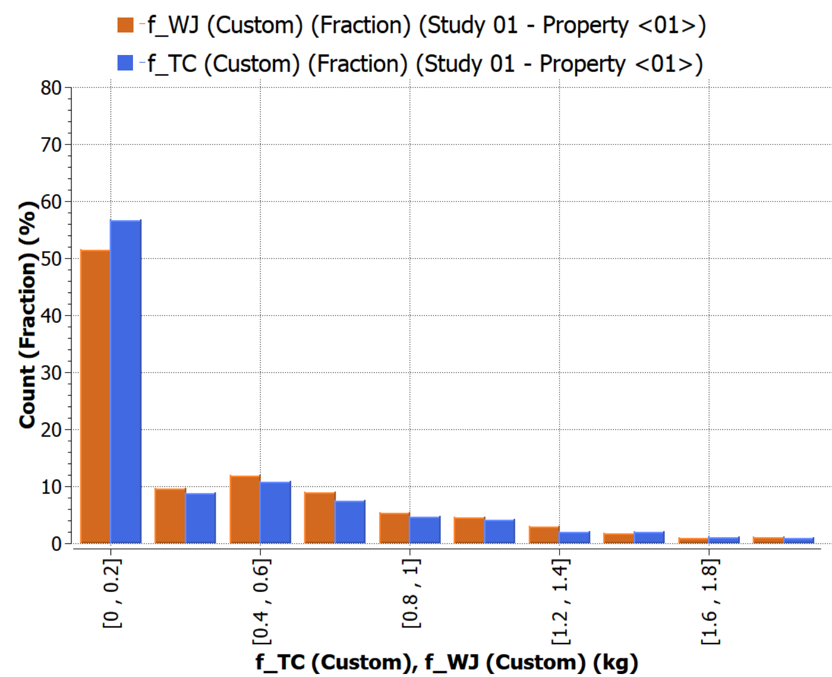
TC4500



EXAMPLE: 혼합 성능 평가

- 히스토그램을 활용하여 특정 시간에서 입자의 분포를 분석
- 본 예시에서는 특정 시간의 입자 크기 분포를 분석하여 혼합 효율을 평가





Base Blade

5. 호환성

INTERACTION OF SOLVER: ROCKY AND FLUENT

Fluid phase

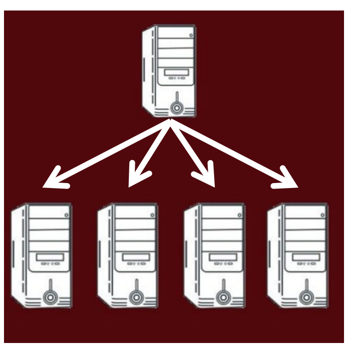
유동 속도

압력 & 온도

Particle phase

부피 비율 (Volume fraction)

관성력 & 열 교환

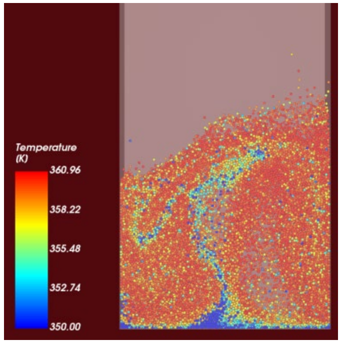


CFD 계산:
CPU 활용

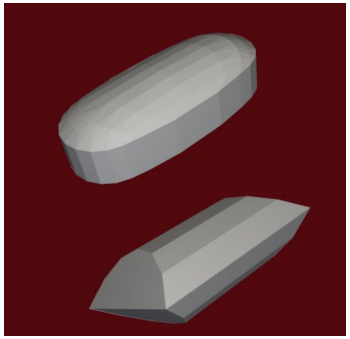
DEM 계산:
GPU 활용
(Single & Multi)

ROCKY-FLUENT UNIQUE FEATURES

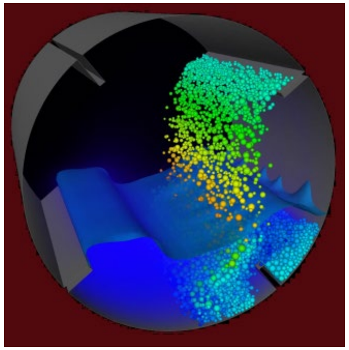
ROCKY – Fluent 연성 해석



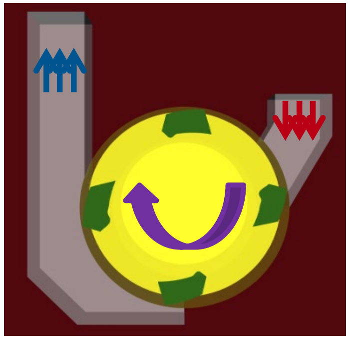
관성력 & 열교환



실제 형상 반영



다상 유동



이동 격자 & 개면 처리
(Moving Meshes & Interfaces, Non-Conformal)

ROCKY-FLUENT COUPLING METHOD

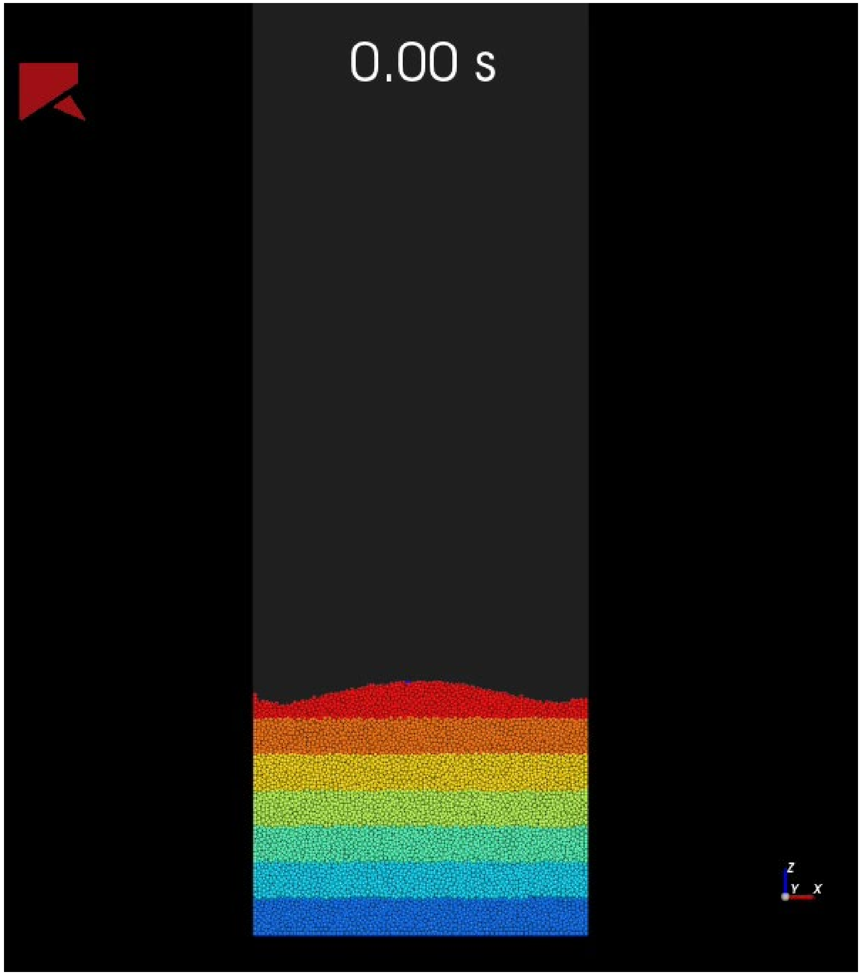
- 관성력 & 열교환

1-way (단방향)

유동 → 입자 거동

2-way (쌍방향)

유동 ↔ 입자 거동



ANSYS Fluent와의 효율적이고 강력한 호환성으로 최적의 연성 해석 환경 제공!

INTERACTION OF SOLVER: ROCKY AND FLUENT

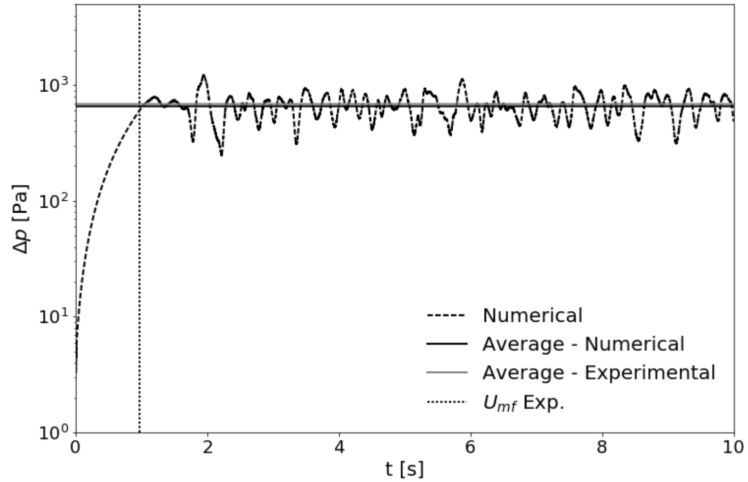
ANSYS Fluent (CFD)와의 연성해석: 단방향 (1-way Coupling)

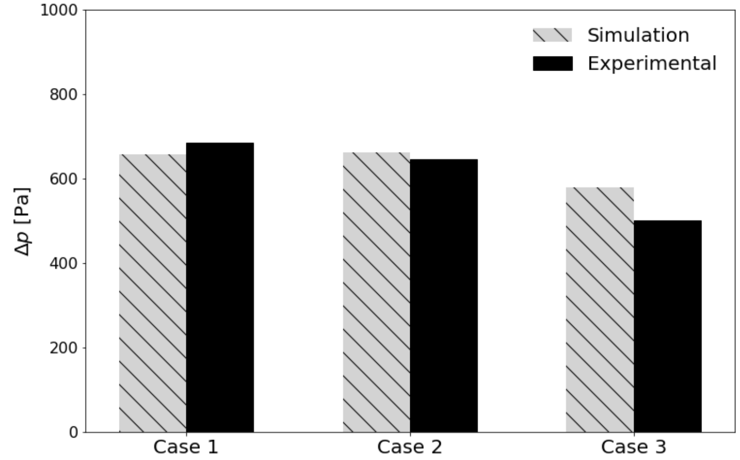
Shape effect 미 고려

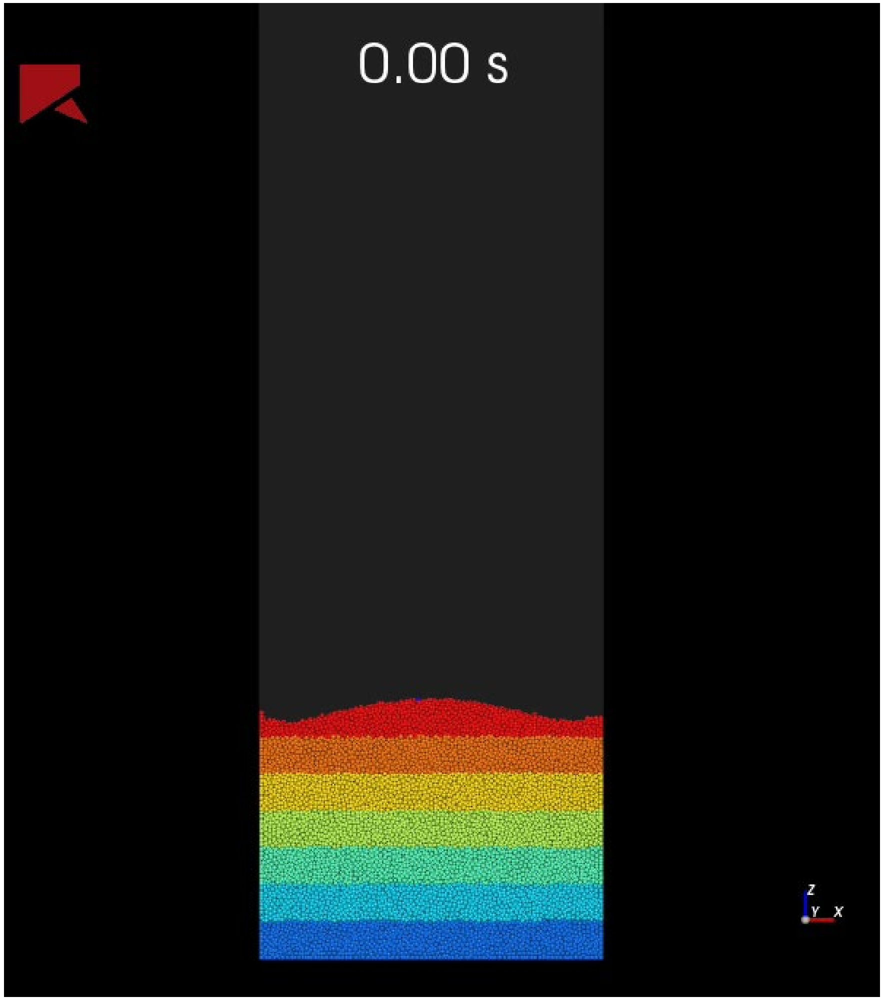
Shape effect 고려

INTERACTION OF SOLVER: ROCKY AND FLUENT

ANSYS Fluent (CFD)와의 연성해석: 쌍방향 (2-way Coupling)

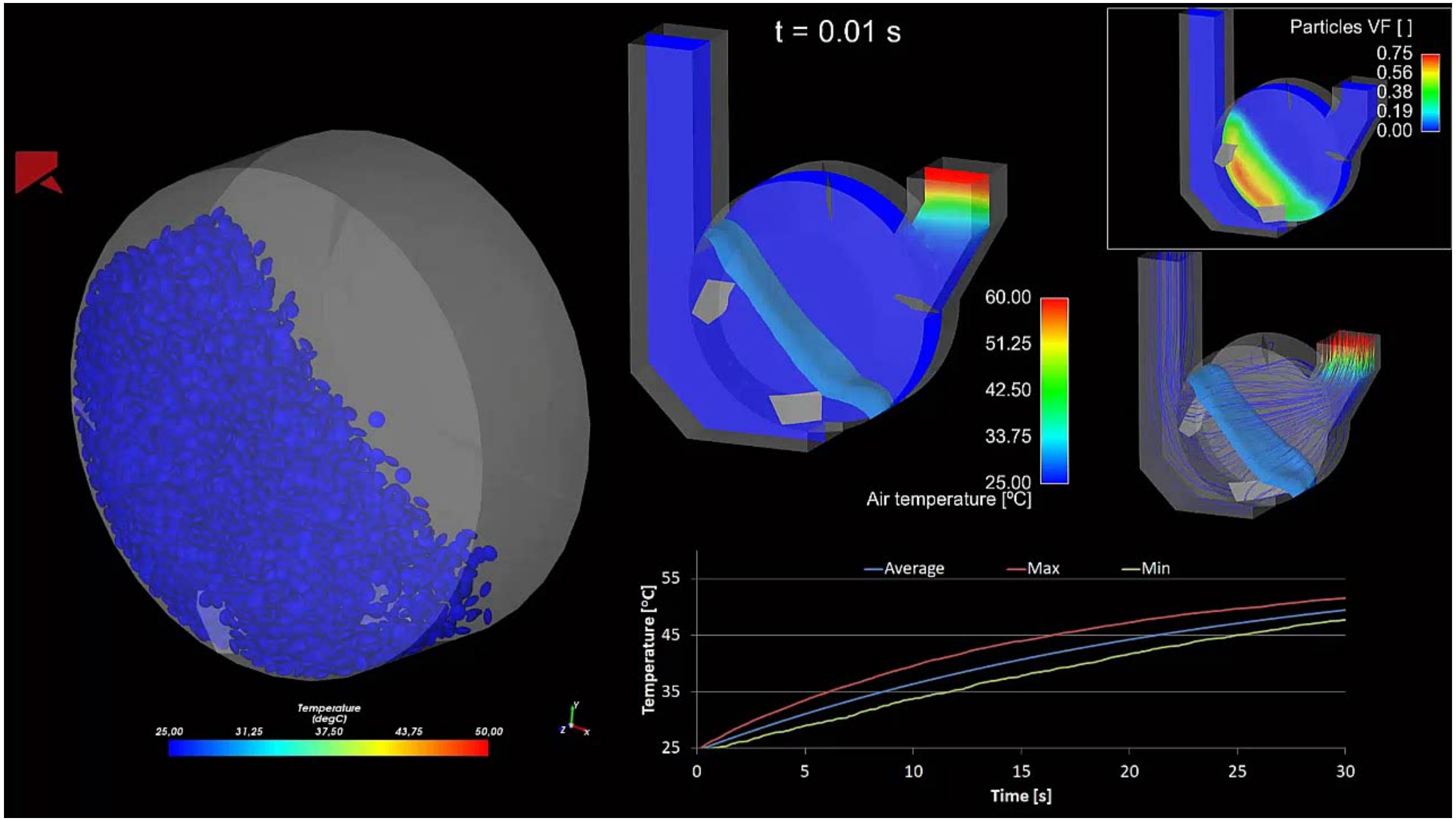






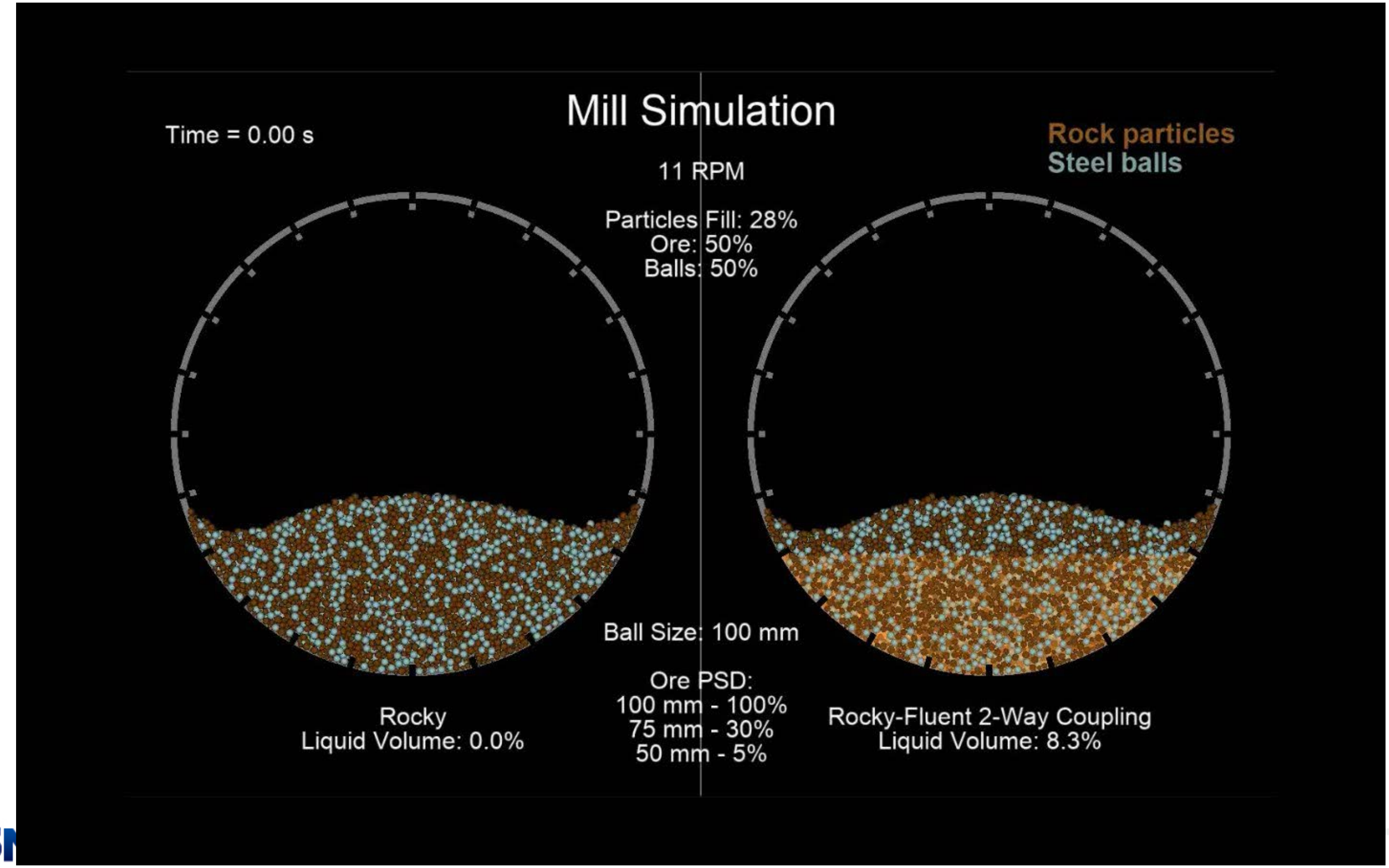
INTERACTION OF SOLVER: ROCKY AND FLUENT

- Multiple Domains, Non-Conformal & Moving Meshes Support
  (다중 도메인, 격자 불일치 & 이동 격자)



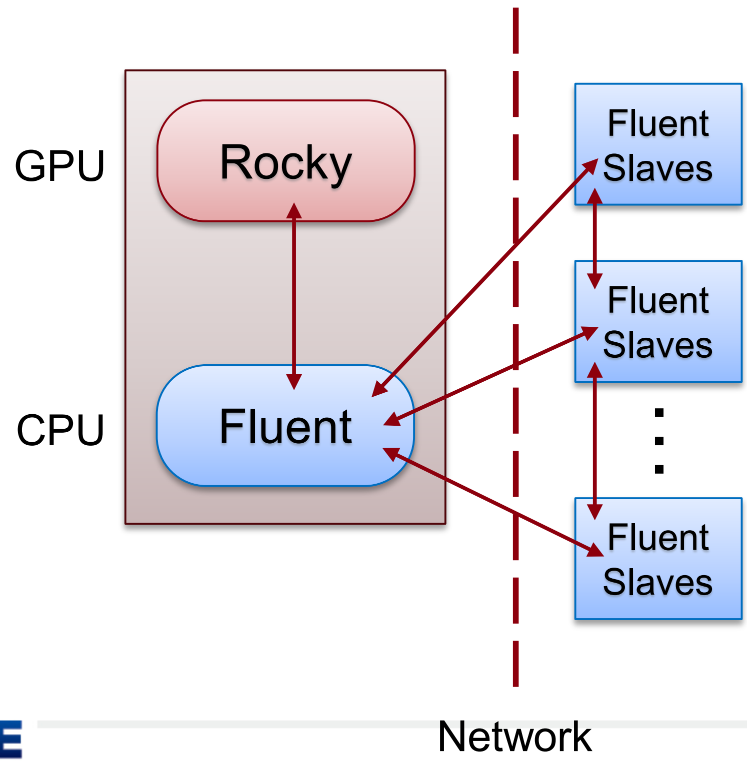
INTERACTION OF SOLVER: ROCKY AND FLUENT

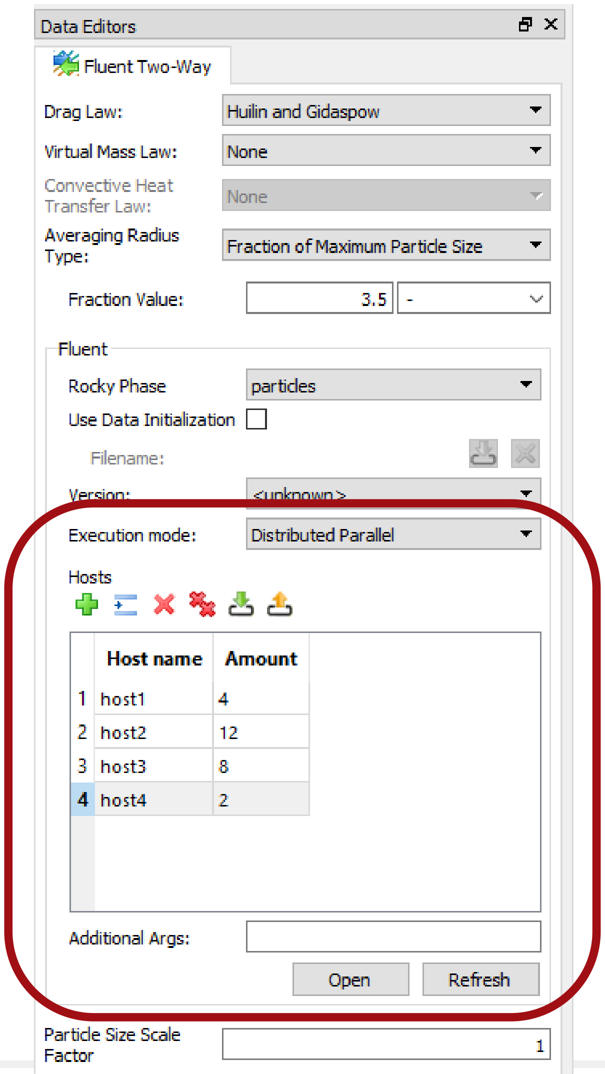
- Multiple Domains, Non-Conformal & Moving Meshes Support
(다중 도메인, 격자 불일치 & 이동 격자)



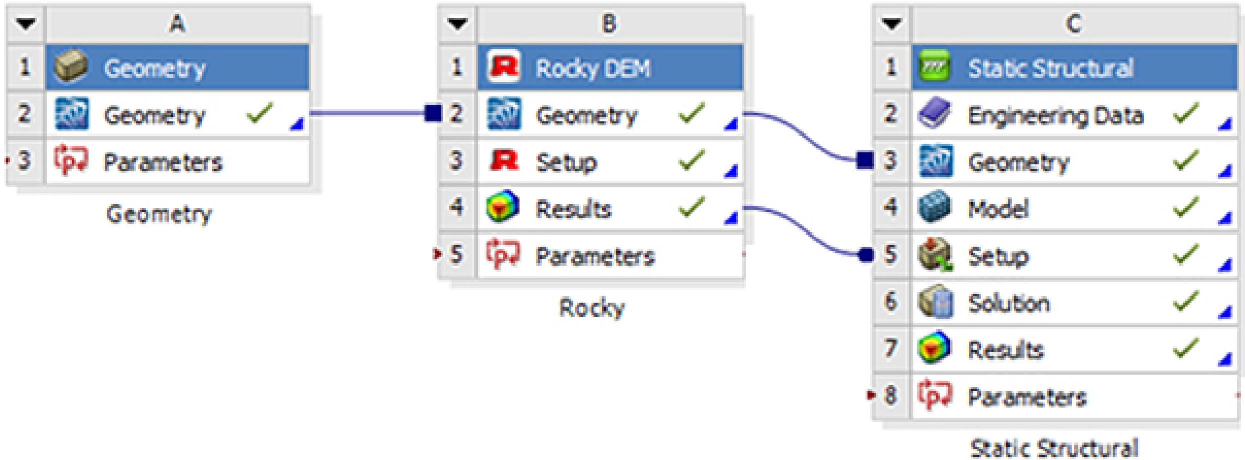
INTERACTION OF SOLVER: ROCKY AND FLUENT

- ROCKY-Fluent coupling 해석 시 Fluent distributed run 기능 제공
  - CPUs for CFD solver
  - GPUs for DEM solver





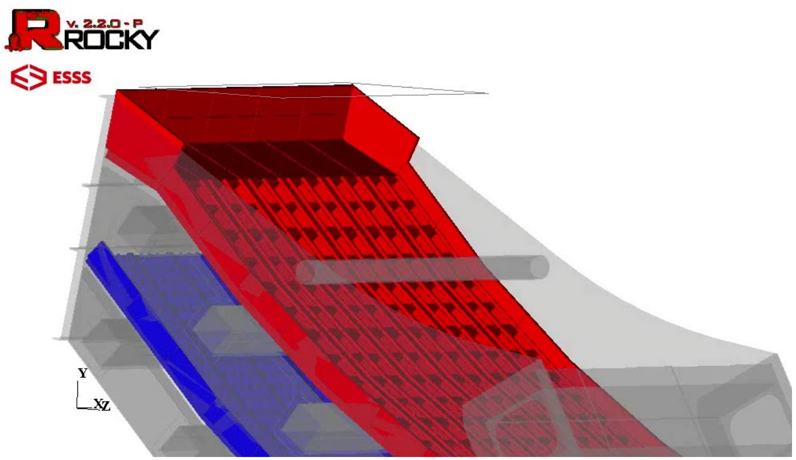
FULLY INTEGRATED WITH ANSYS TOOLS

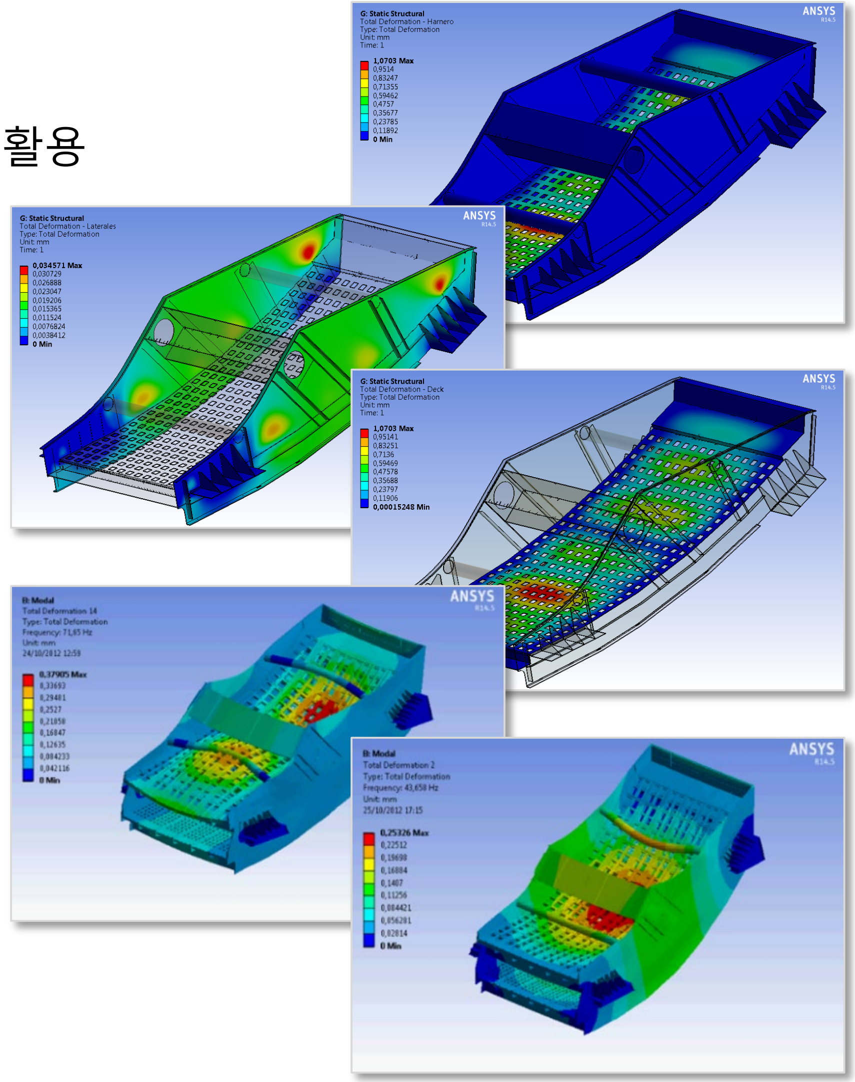


- ANSYS Workbench에서 component로 활성화 가능
- 입자 및 주변 구조의 geometry 생성 및 수정 시 **ANSYS SpaceClaim** 활용
- ANSYS Structural (FEA solver) 및 ANSYS Fluent (CFD solver)와의 완벽한 호환
- ANSYS Workbench에서 ROCKY의 파라미터를 수정하여 Case study 및 최적화 해석 수행 가능

FULLY INTEGRATED WITH ANSYS TOOLS

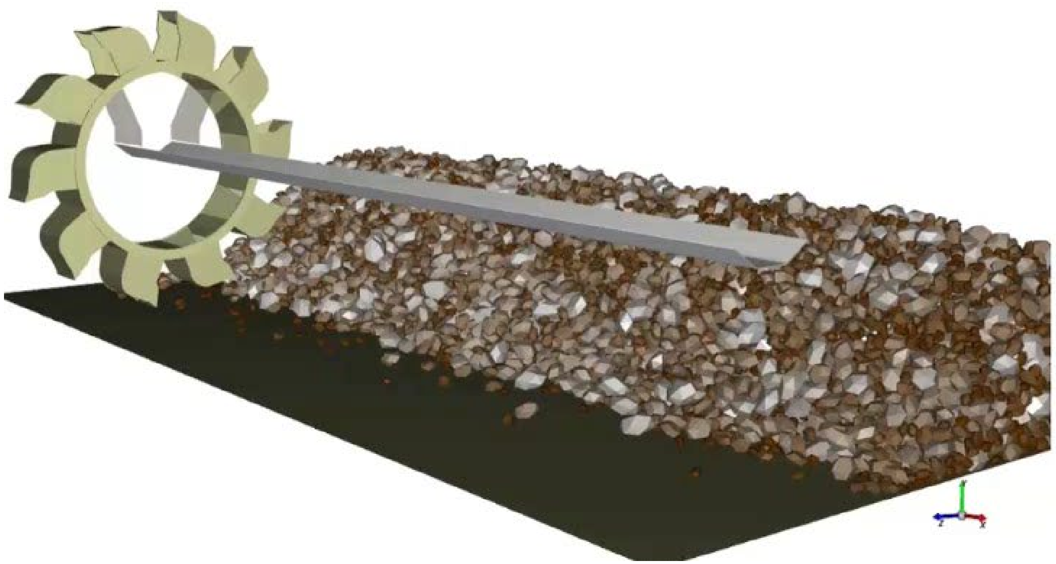
- ANSYS Mechanical Coupling (Static)
  - ROCKY의 해석 결과를 구조해석 하중으로 활용

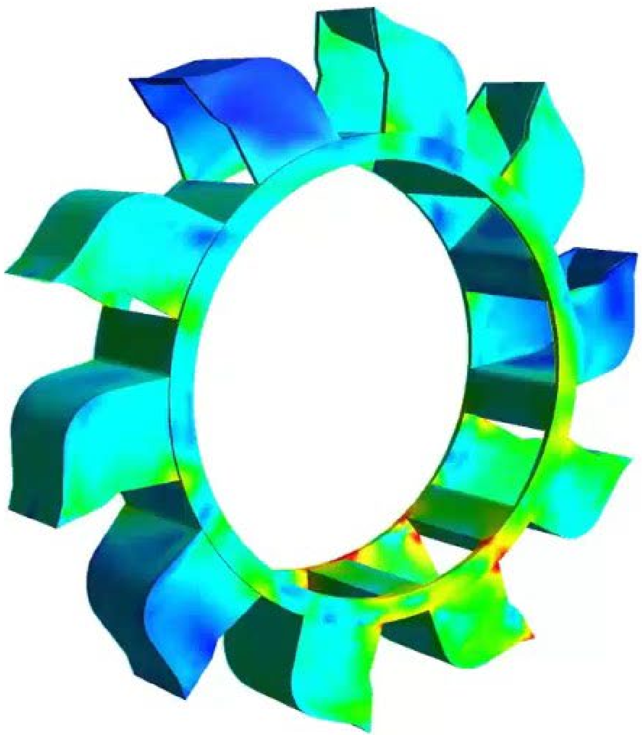




FULLY INTEGRATED WITH ANSYS TOOLS

- ANSYS Mechanical Coupling (Transient)
  - ROCKY의 해석 결과를 구조해석 하중으로 활용





- Particle induced loads captured accurately

FULLY INTEGRATED WITH ANSYS TOOLS

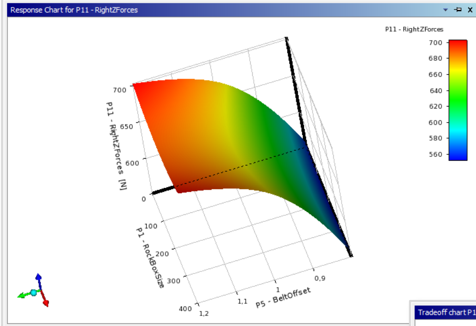
ANSYS DesignXplorer Coupling

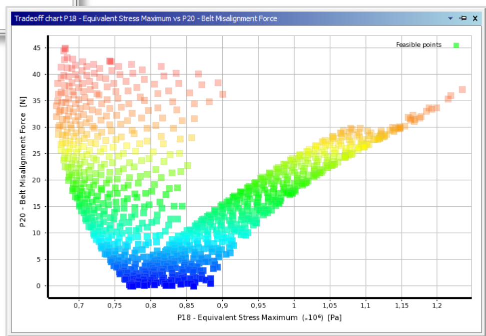
- Input and Output Parameters

Outline of Schematic D2: Design of Experiments

	A	B
1		Enabled
2	Design of Experiments	
3	Input Parameters	
4	Geometry (A1)	
5	P1 - RockBoxSize	☑
6	P3 - RockBoxAngle	☐
7	P15 - RockBox1	☐
8	P16 - RockBox2	☐
9	P17 - RockBox3	☐
10	Rocky DEM (B1)	
11	P4 - FeedBeltVelocity	☐
12	P5 - BeltOffset	☑
13	P6 - MassFlow	☐
14	P7 - ReceivingBeltVelocity	☐
15	Output Parameters	
16	Rocky DEM (B1)	
17	P10 - LeftZForces	
18	P11 - RightZForces	
19	Static Structural (C1)	
20	P18 - Equivalent Stress Maximum	
21	P19 - Total Deformation Maximum	
22	P20 - Belt Misalignment Force	
23	Charts	

- Automated project-level update mechanism
- Pervasive parameter management
- Integrated optimization tools





6. SUMMARY

SUMMARY

실제 형상을 구현한 입자 형태로 해석

CAD 및 3D scanner를 활용한 입자 형태 구현

입자 파손

입자의 접착성을 고려한 해석 가능

Double-Precision

Multi-GPU 지원

ROCKY

구조물 표면 마모 평가

ANSYS와의 완벽한 호환성

강력한 모션 구현 엔진

효율적인 CAD 파일 활용 기능

유선 계산 및 포스팅 기능 (Streamlined Calculations)

다양한 해석 결과 포스팅 기능

해석 결과에 대한 강력한 동영상 제작 기능

BOSCH
MULTOTEC
TAKRAF TENOVA
FLSmidth
SANDVIK
amec
acensium llc
Risks, Hazards, Losses—CONTROLLED
PMC PROJECTS (INDIA) PRIVATE LIMITED
from vision to reality...
WorleyParsons
resources & energy
ThyssenKrupp
abe
tradition • innovation • quality
ANGLO AMERICAN
Excellent Minerals Solutions
WEIR MINERALS
TUNRA BULK SOLIDS
TAKRAF tenova TAKRAF
Axis Engineering
ATEC PMC
innovative project solutions
calibre MINERVA
VALE
BRADKEN
BMT WBM
PEPSICO
GBM Liberating Your Natural Resources
ENGINEERING • PROCUREMENT • CONSTRUCTION • PROJECT MANAGEMENT
MEPSA
METALURGICA PERUANA S.A.
chemtech
A Siemens Business
TECNIPAK
TECNOLOGIAS DE MEJORAMIENTO PRODUCTIVO
DMW
DEARBORN MID-WEST COMPANY
COVE ENGINEERING
De Beers
Group of Companies
MMD
ELECON
GEARING THE FUTURE
ESSAR PROJECTS
epc
MARSHALL MULTISPREAD
NIPPON STEEL & SUMITOMO METAL
HATCH
Panasonic
GPC
Gladstone Ports Corporation
Growth, Prosperity, Community.
JACOBS
LAING O'ROURKE
PT. GROWTH ASIA
A Member of the Growth Steel Group
JOYGLOBAL
GHD
INCAD SERVICE
tSNE
LIEBHERR

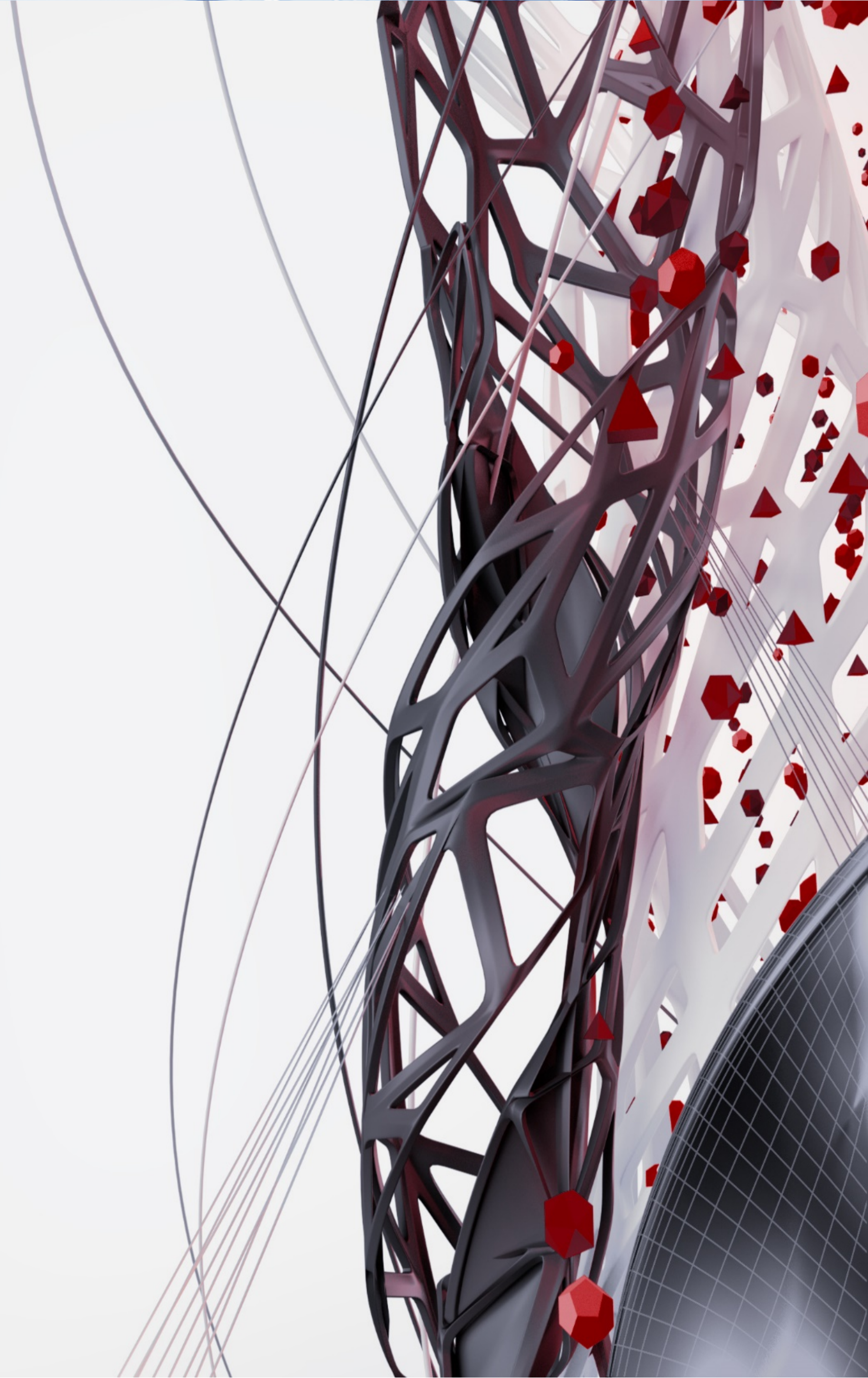
ROCKY

Rocky 4.3 Release Update

May/2019

Marcus Reis & Clovis Maliska Jr.

ESSS



CFD Coupling Enhancements

- Single Fluid Phase Approach
- Lagrangian - Eulerian Mapping
- Turbulence Energy Support

Physics Enhancements

- CGM (Coarse Grain Modeling)
- Discrete Breakage (fiber, shell & solid)
- Liquid Bridge Model
- Cylindrical Periodic Boundary Conditions

PrePost Workflow Productivity

- Volume Filling Initialization
- Contact Data Visualization & Post-Processing
- Ray Casting Post-Processing

CFD Coupling: Single Phase Fluid Approach

1 Fluid + Solids: NEW 4.3

- Single-Fluid: Single Phase +

  Po… a

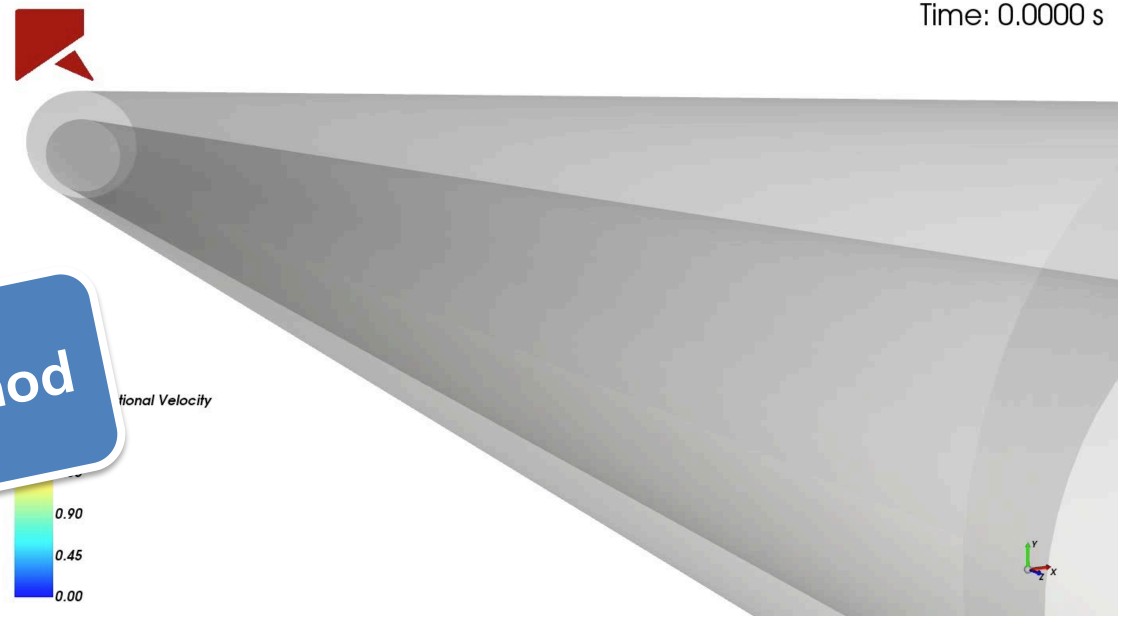
~3x Faster

2+ Flu… + Solids:

- Multiphase: E…
-

Easy Fluent Setup
(w/ broader range of mod els)

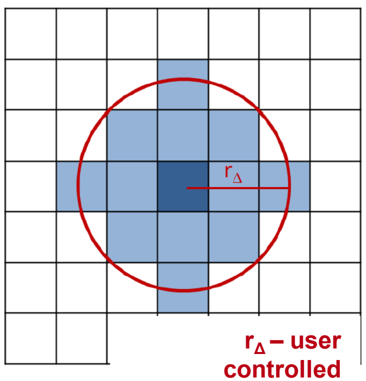
Gravel Packing Example

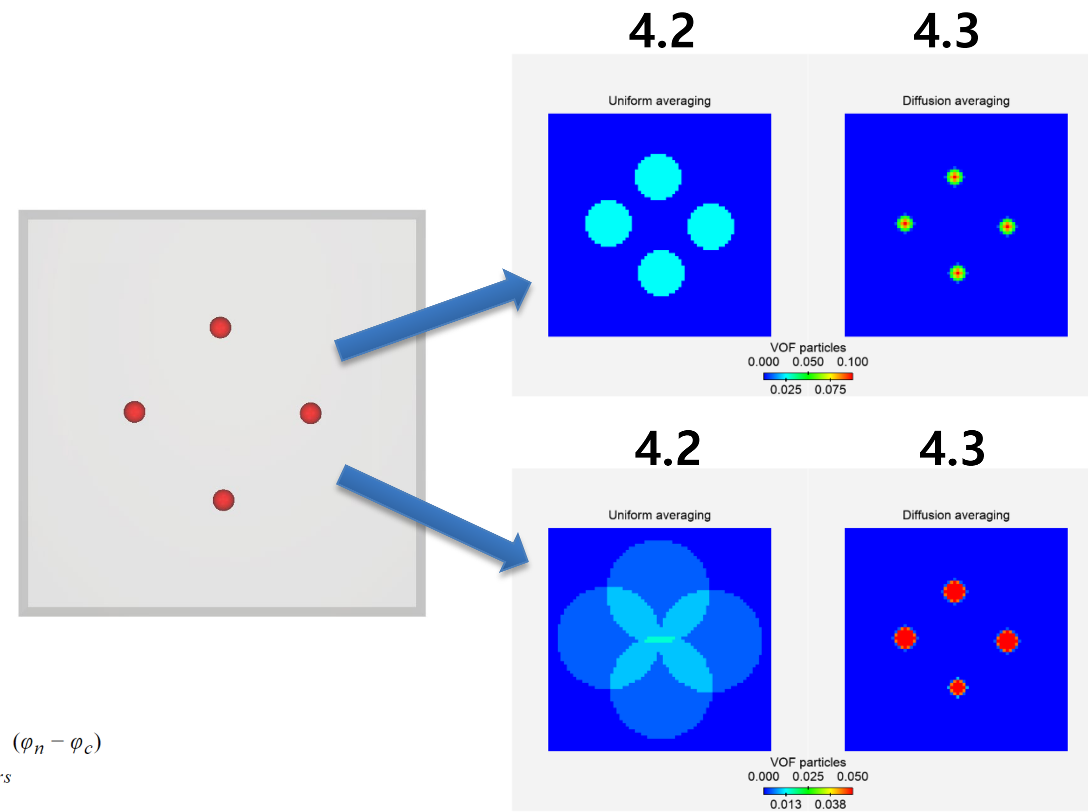


CFD Coupling: Lagrangian - Eulerian Mapping

Rocky 4.2 + Fluent

Coupling Super-cel





Rocky 4.3 + Fluent

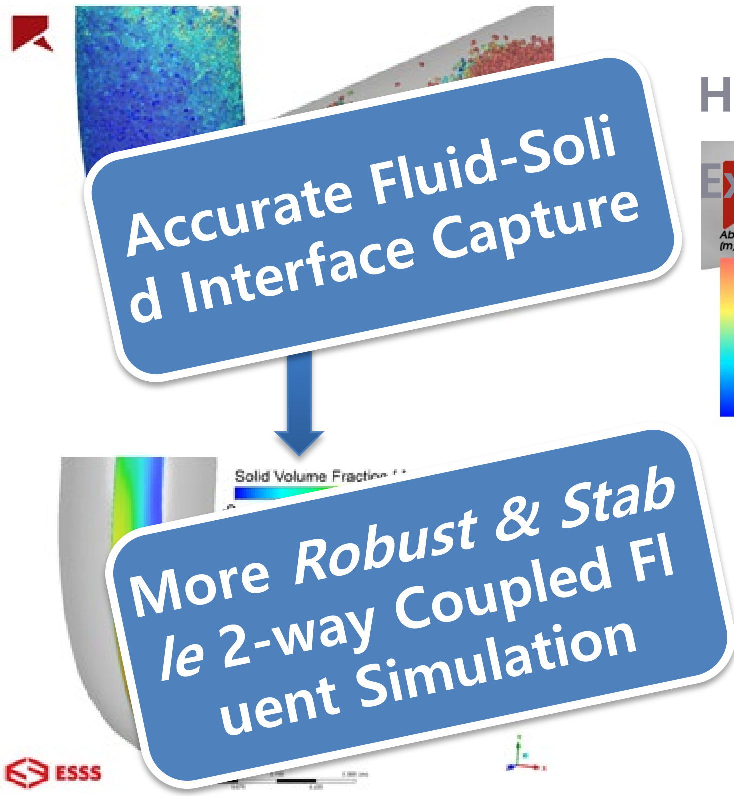
Cou

$$\frac{\partial \varphi}{\partial t} = D\nabla^2 \varphi$$

$$\varphi_{c,\,new} = \varphi_c + \frac{K}{V_c} \sum_{n\,:\,neighbors} (\varphi_n - \varphi_c)$$

$$K_c = \frac{V_c}{2{*}N_c}$$

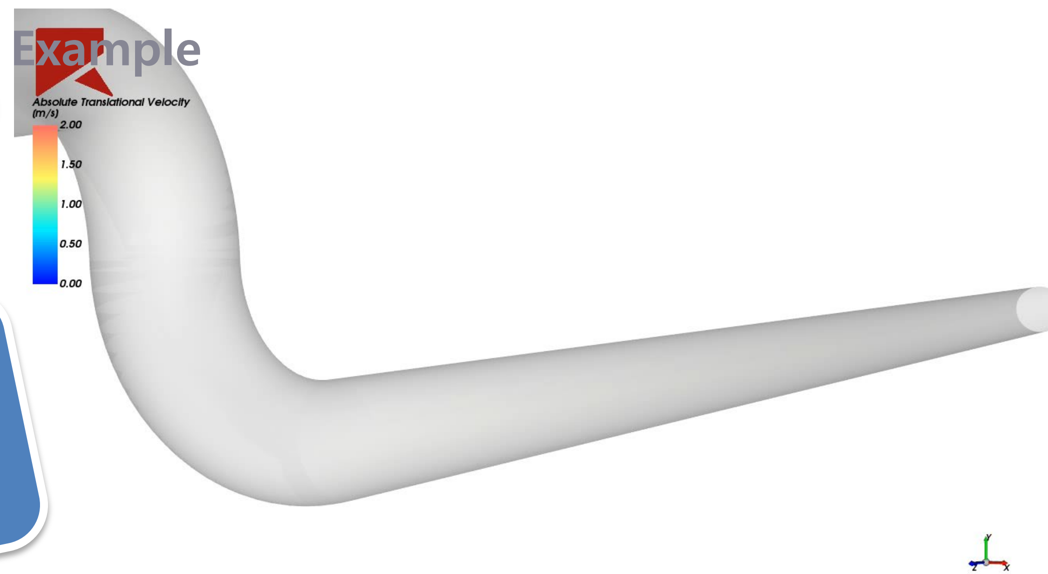
CFD Coupling: Lagrangian - Eulerian Mapping



Accurate Fluid-Solid Interface Capture

More *Robust & Stable* 2-way Coupled Fluent Simulation

Hidraulic Transport Example



CFD Coupling: Turbulence Energy Support

4.2 – Laminar Only

4.3 – Laminar + Turbulence

CFD Coupling: Turbulence Energy Support

High Flow Speed w/ Small Particles

15MM Particles
100 μm, ~100 m/s

Velocity

High Fidelity DEM-CFD Coupled Solution

Temperature

CGM (Coarse Grain Modeling)

Systems w/ Huge Amount
of Particles (e.g. Powders)

Billions/Trillions of Particles

(impossible to model 1:1)

Parcel Approach

Automatic UX for Particle Scale Up/Down for DEM-only & CFD-DEM Systems

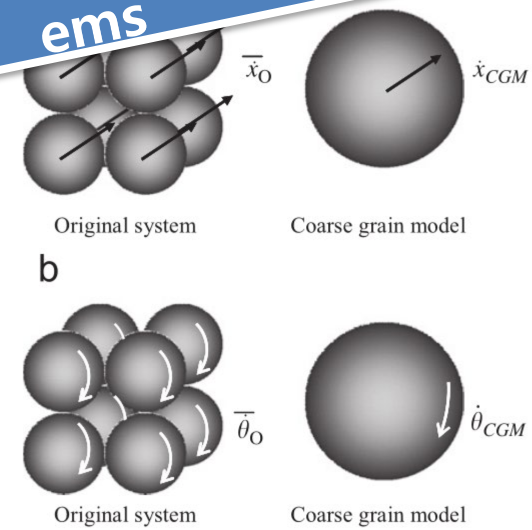


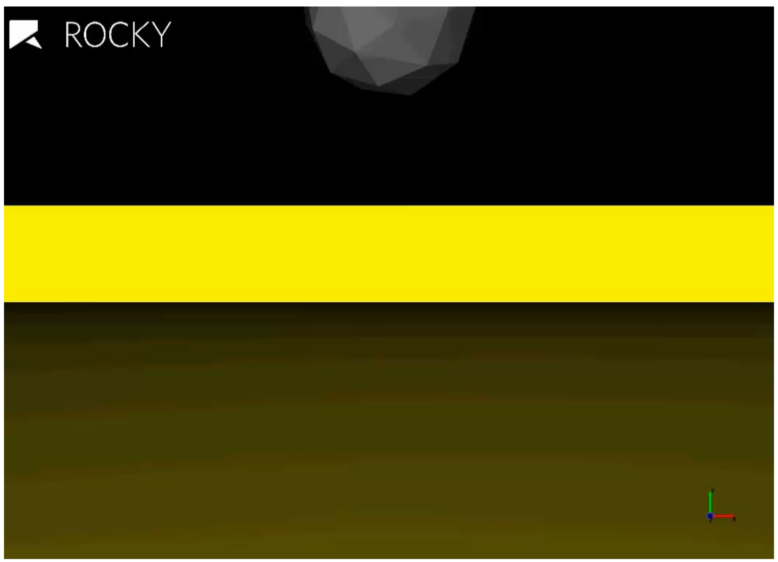
Fig. 3. Coarse grain model. (a) Translation; (b) rotation.

Discrete Breakage

Instant Fragmentation (4.2)

Shape & Collision Location *Independent*

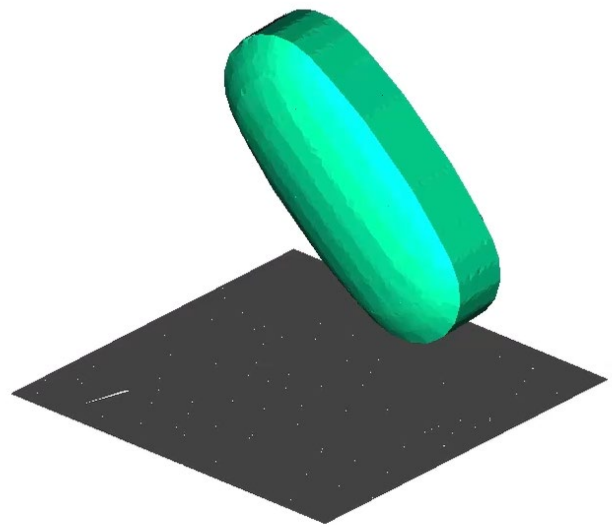
- Based on total collision energy
- Validated for mining equipment (natural brittle material)



Discrete Breakage (4.3!)

Shape & Collision Location ***Dependent***

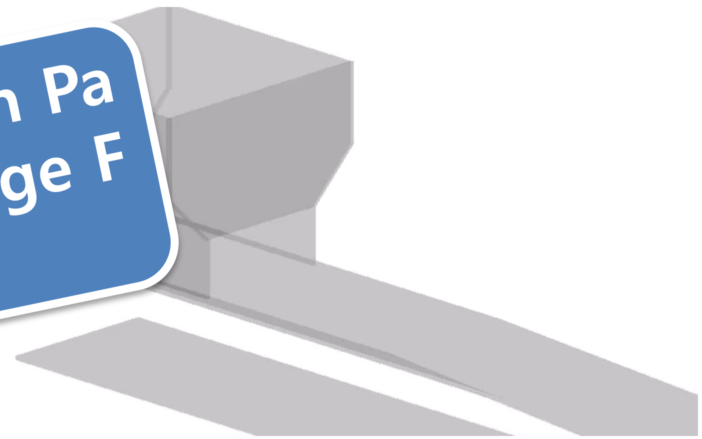
- Internal stresses are computed (“mini-FEA”)
- Local stress breakage criteria



Discrete Breakage

Fiber

Shell



Next Level on Particle Breakage Fidelity!

Particle type dependent criteria

- Fiber, Shell or Solid

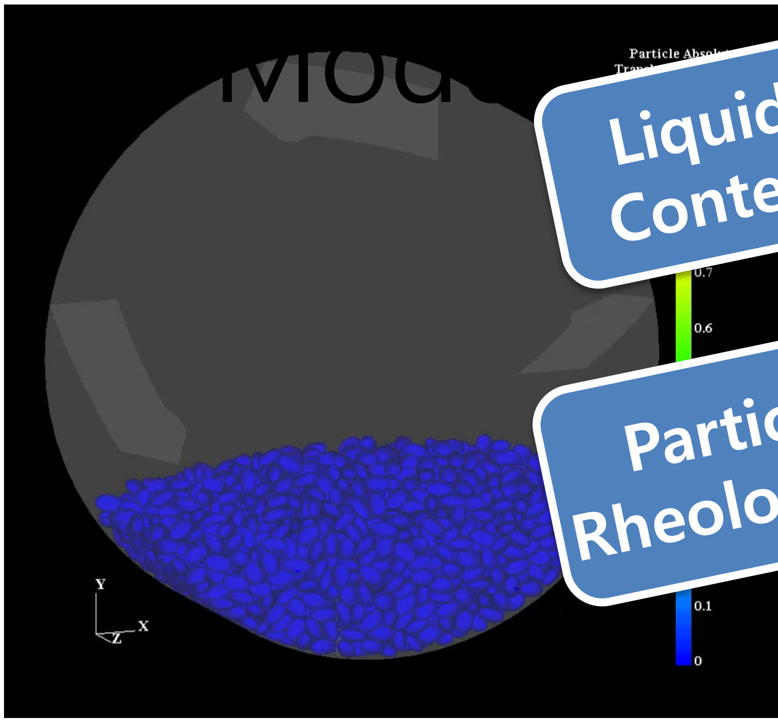
Multiple stress-based breakage criteria

- Normal, Bending, Shear and/or Torsional

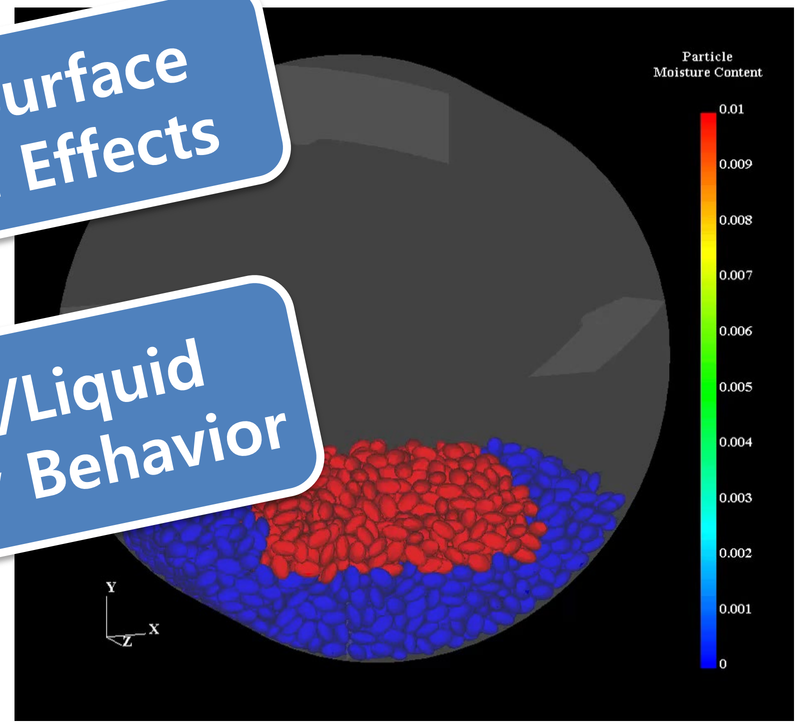
Liquid Bridge Model

Liquid Surface Content Effects

Particle/Liquid Rheology Behavior

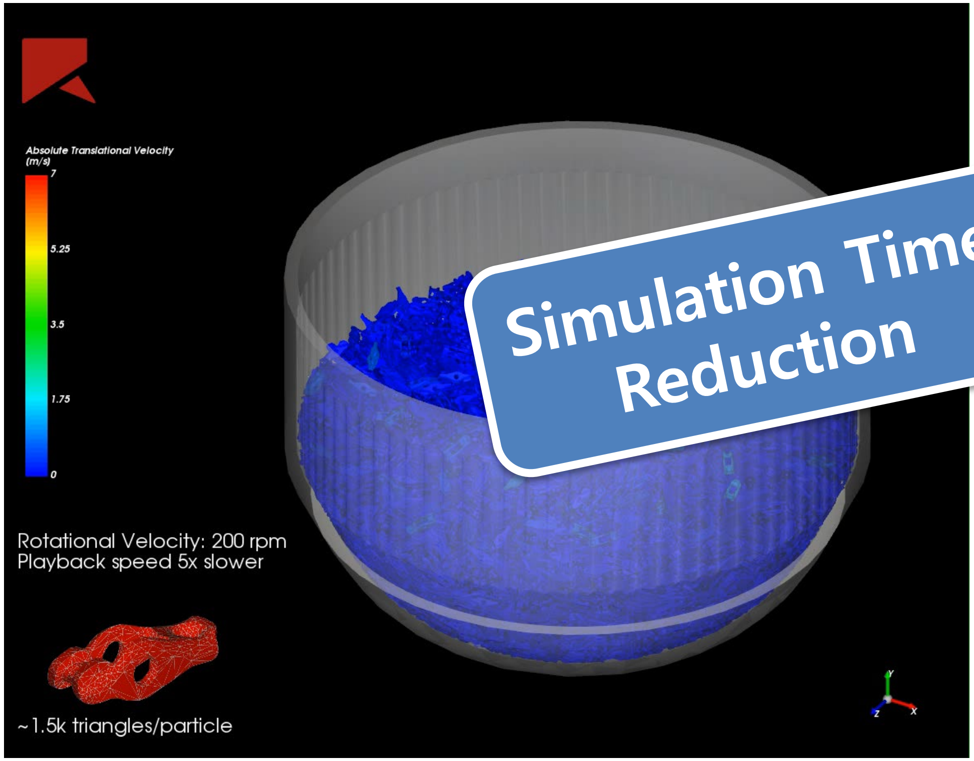


Dry Particles (Translational Velocity)

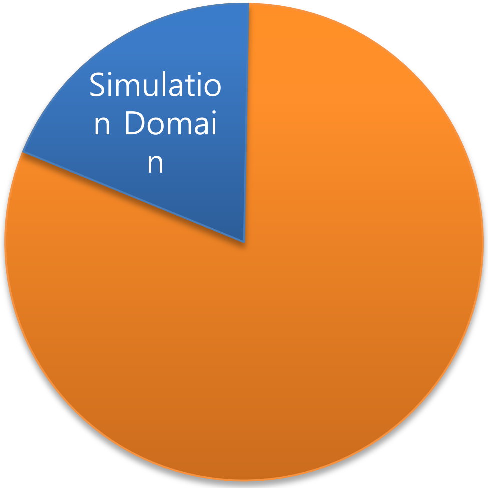


Wet Particle (Liquid Content)

Cylindrical Periodic Boundary Conditions



Simulation Time Reduction



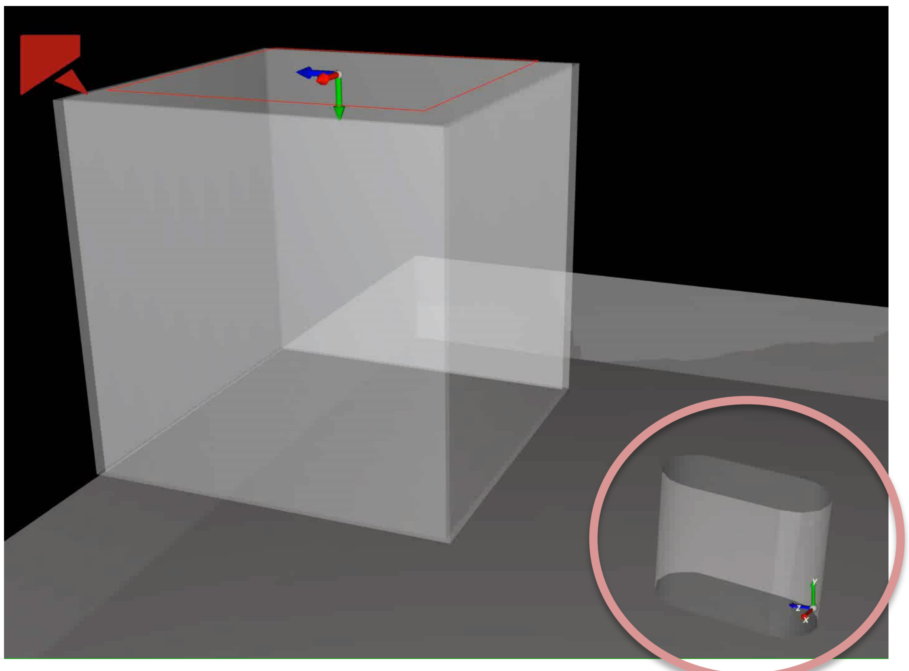
90 degrees
4x faster

Volume Filling Initializ

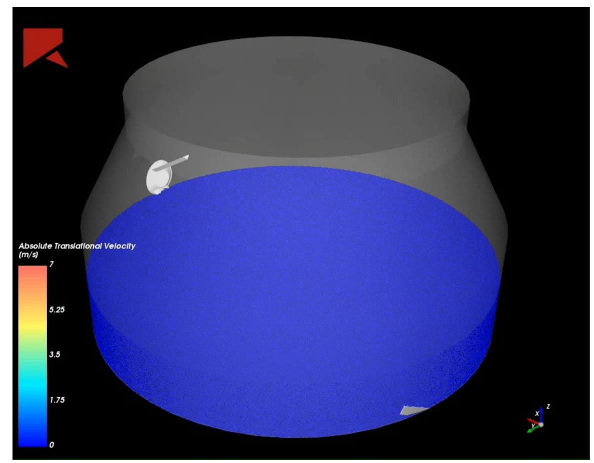
85x Faster!

(Flood Filling Method)

14.3MM Particles

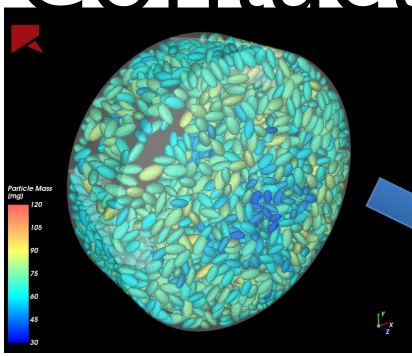


Inlet Filling
~21 hours → Volume Flood Filling
~10 minutes!

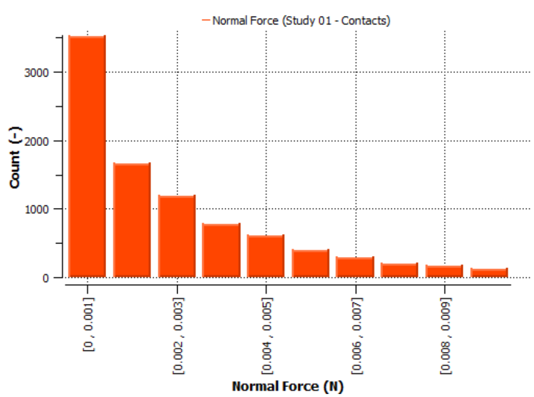


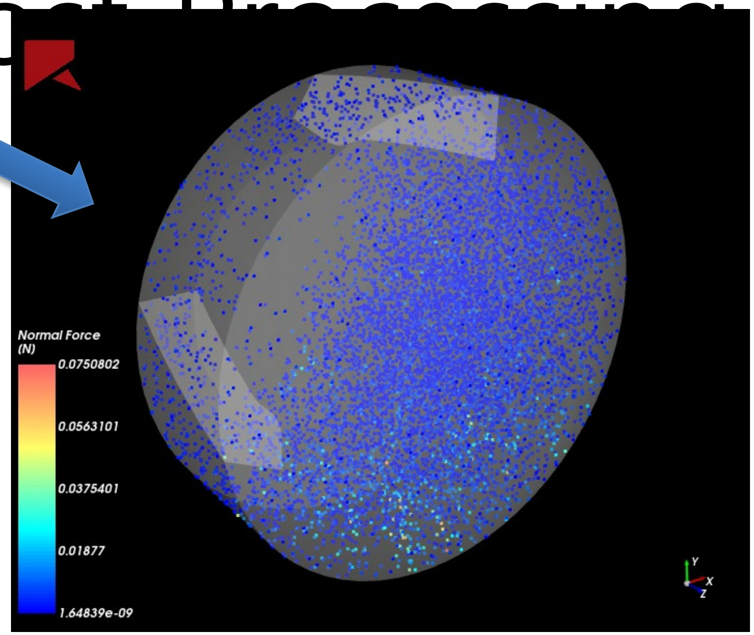
4.3
Spheres
with PSD → 5.0
General Particle
Containing Sphere

Contact Data Visualization & Post-Processing

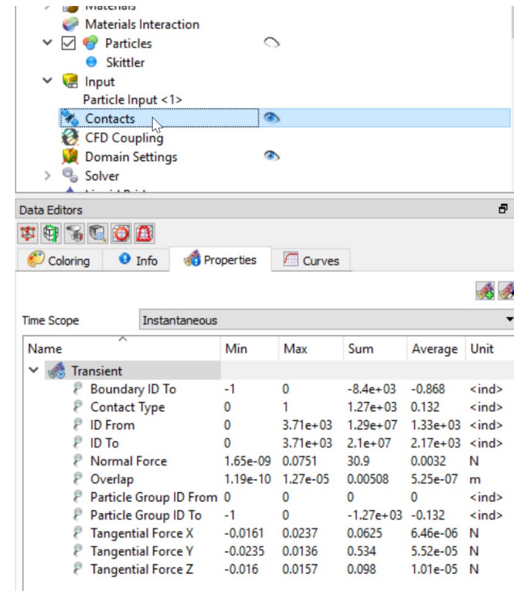


Particles



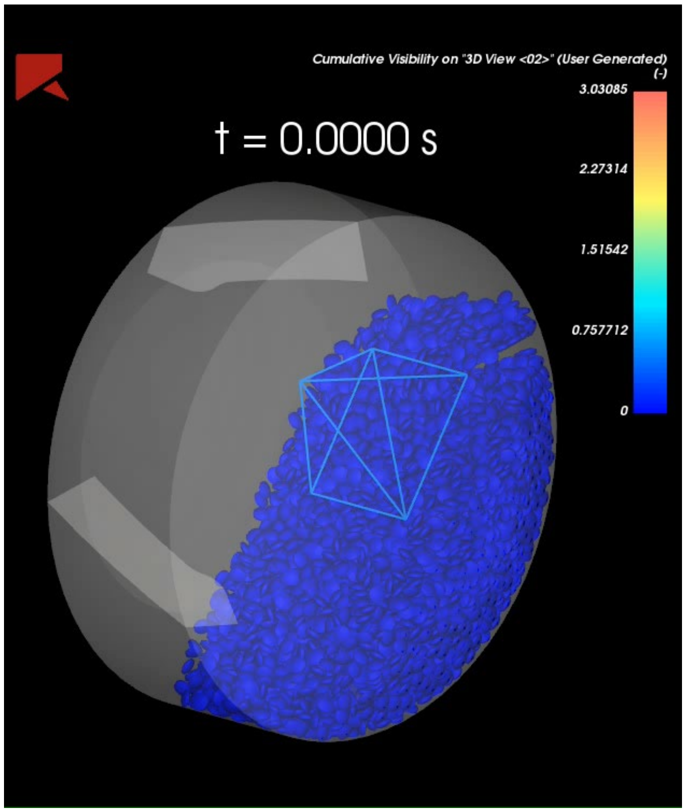


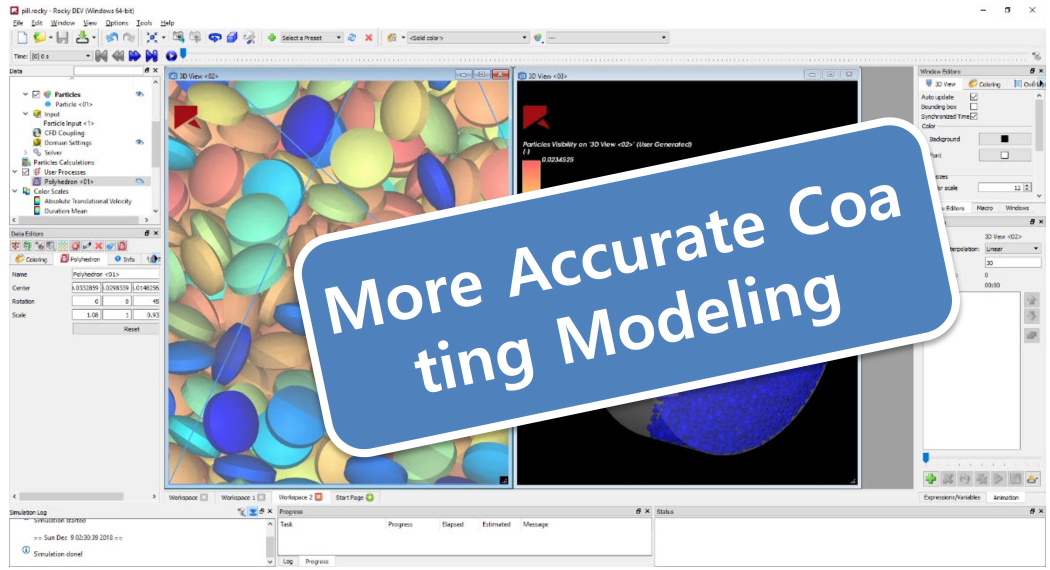
Contacts



Available on the Post-Processing Script API

Ray Casting Post-Processing





- **Particle Partial/Total Occlusion**
- **OpenGL Hardware Rendering**