Numerical simulations of solid material fragmentation - the Discrete Element Method approach

W. Dębski

IGF PAS, Warsaw

The lecture has been (partially) financed from the funds of the Leading National Research Centre (KNOW)

received by the Centre for Polar Studies for the period 2014-2018

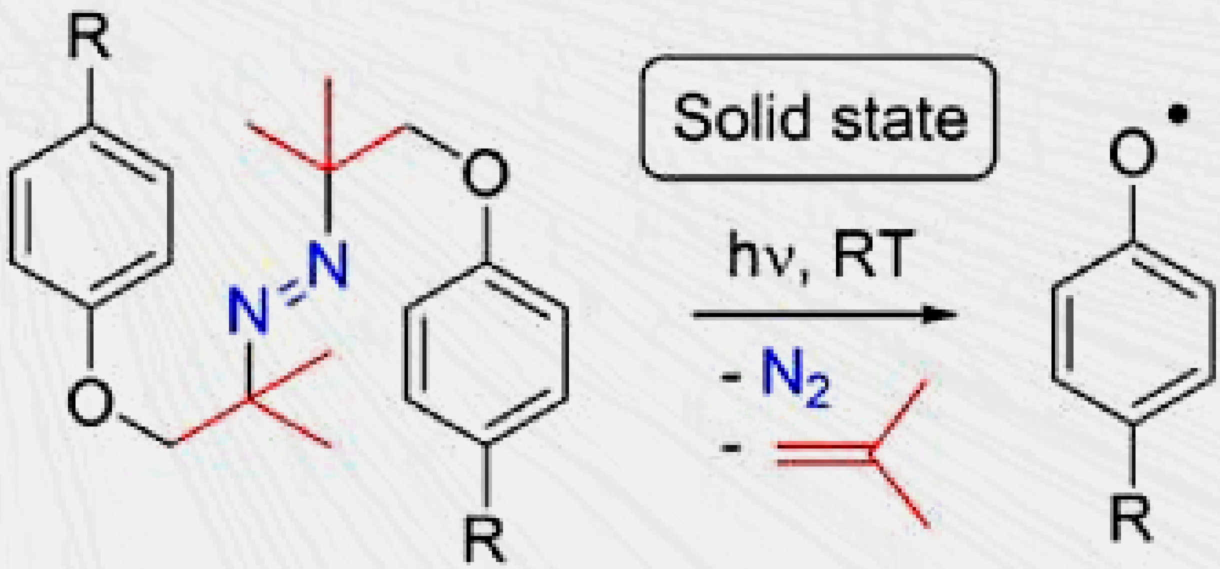
Plan of the talk

- Motivation
- Simulation methods
- Fiber Bundle Method
- Discrete Element Method
  - Thin film under tension
  - Brazilian test
  - “Shooting” ball

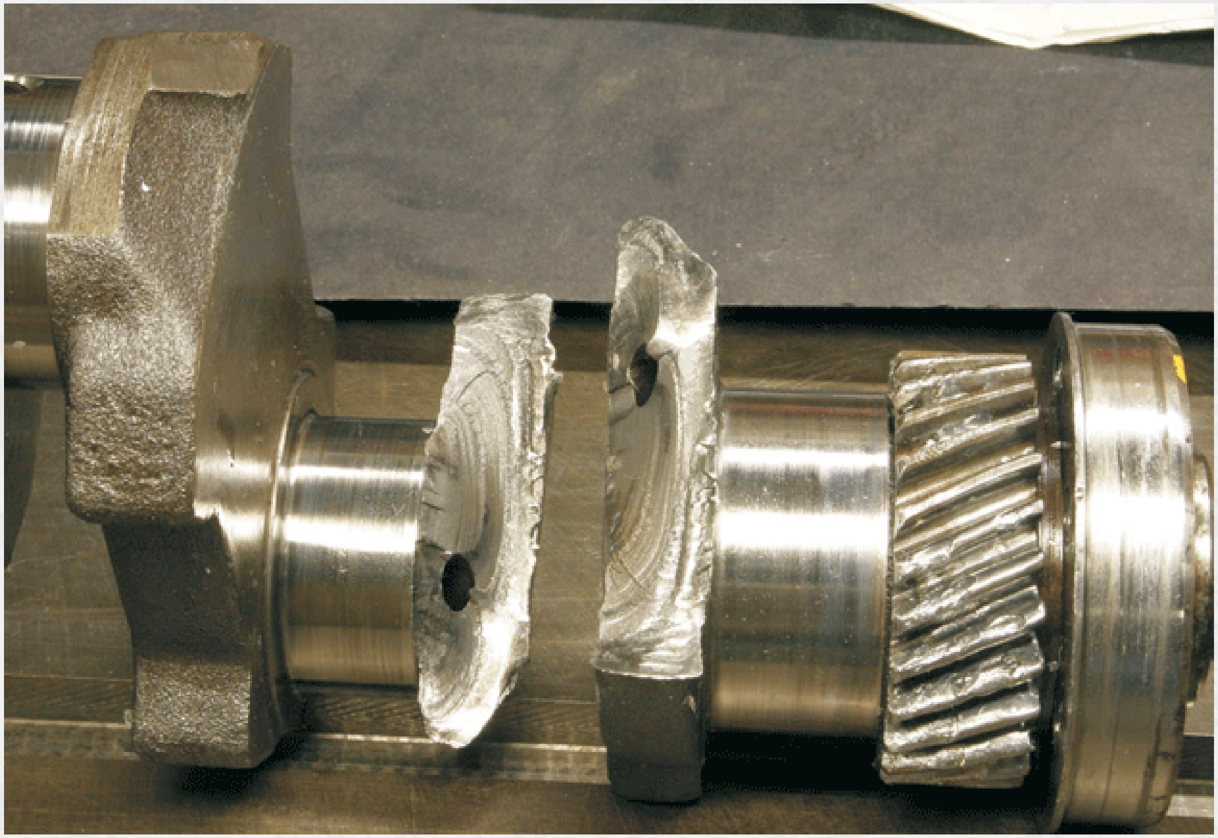
Motivation

Breaking and fragmentation of solid materials is an extremely complex process involving scales ranging from an atomic scale (breaking inter-atomic bounds) up to thousands of kilometers in case of catastrophic earthquakes; in energy scale - from- eV 10^{-19} **J** up to 10^{24} **J**. Such a large scale span of breaking processes opens lot of questions like, for example, scaling of breaking processes, existence of factors controlling final size of broken area, existence of precursors, dynamics of fragmentation, to name a few.

Examples



Examples



Examples

Examples

Examples

Examples

How to simulate breaking process ?

Two important features of breaking processes of solid materials:

Breaking process

1. Breaking is always acompanied by creating new free surfaces (fracturing, fragmentation, void openings).

2. Breaking process always includes some degree of stochasticity

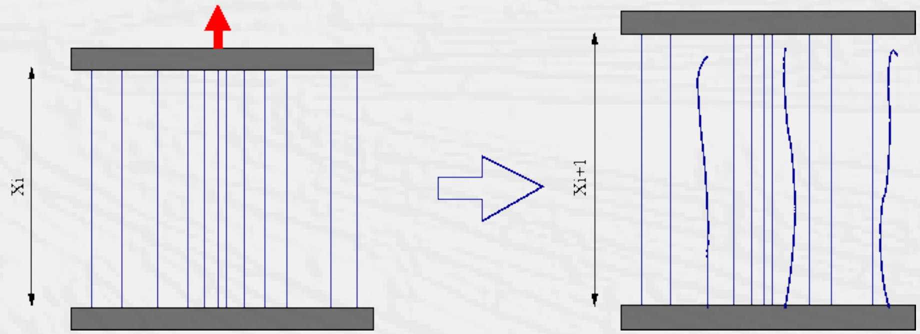
Simulation chalanges

Used simulation method should encapsulated thease features.

Simulation Methods

- Finite Difference Method
- Finite/Spectral Element Method
- Hybrid Finite Element Method
  (FEM with breaking inter-cell connections)
- Boundary Element Method
- Discrete Element Method
- Fiber Bundle Method

Fiber bundle method



Elastic fibers: $F = -kx$

threshold length - independent random variable:

$$x^k : \qquad P(x^k < x) = \int_0^x p(y)dy$$

average total force at clamp

$$F(x) = Nkx(1-x)P(x)$$

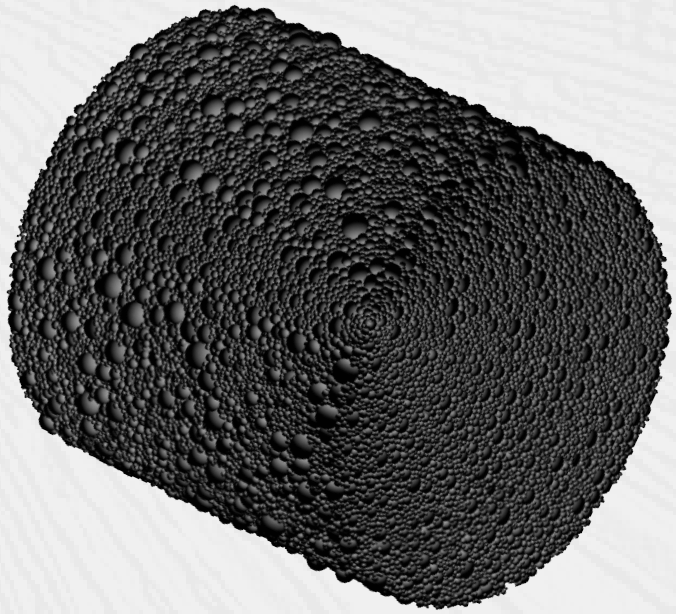
Discrete Element Method

Discrete Element Method (Cundall 1979) relays on a representation of a medium as a discrete set of particles (grains, molecules, etc.) which interact each other in a prescribed way. Dynamic evolution is obtained by a direct solving of multi-body problem.

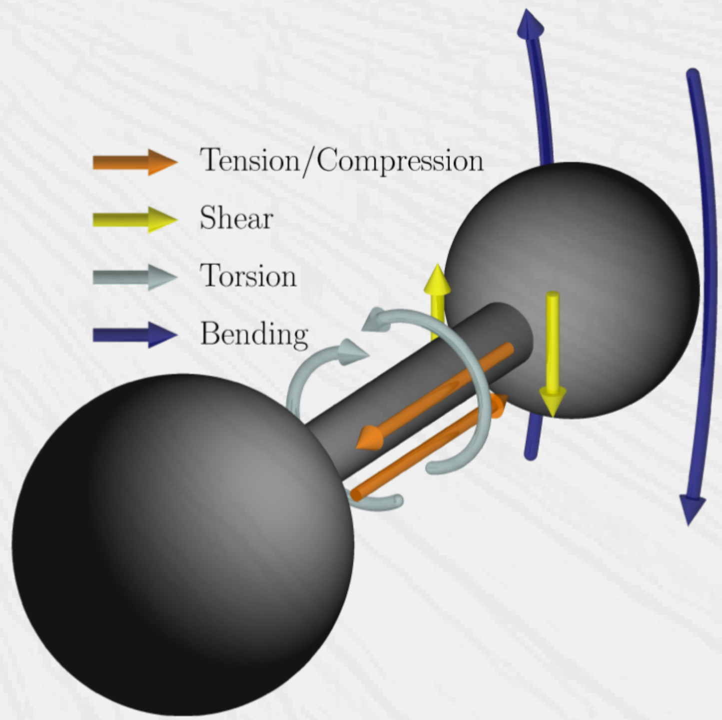
Key steps:

- parameterization
- particle interactions
- temporal evolution

Discrete Element Method - 1: parametrization



Discrete Element Method - 2: particle interactions



Discrete Element Method - 3: time evolution

for each particle:

- calculate summary force

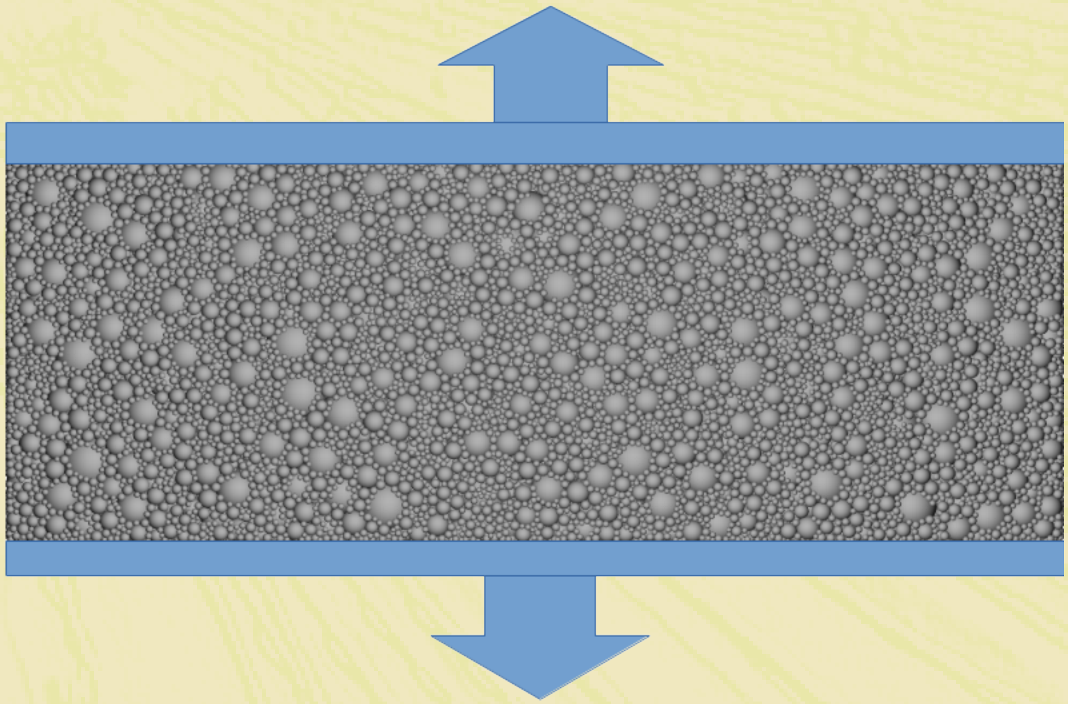
$$u_i(t) \Longrightarrow \bar{F}(u_j(t))$$

- update position, velocities, etc.

$$u_i(t+dt) = u_i(t) + \bar{F}(u_j(t))dt$$

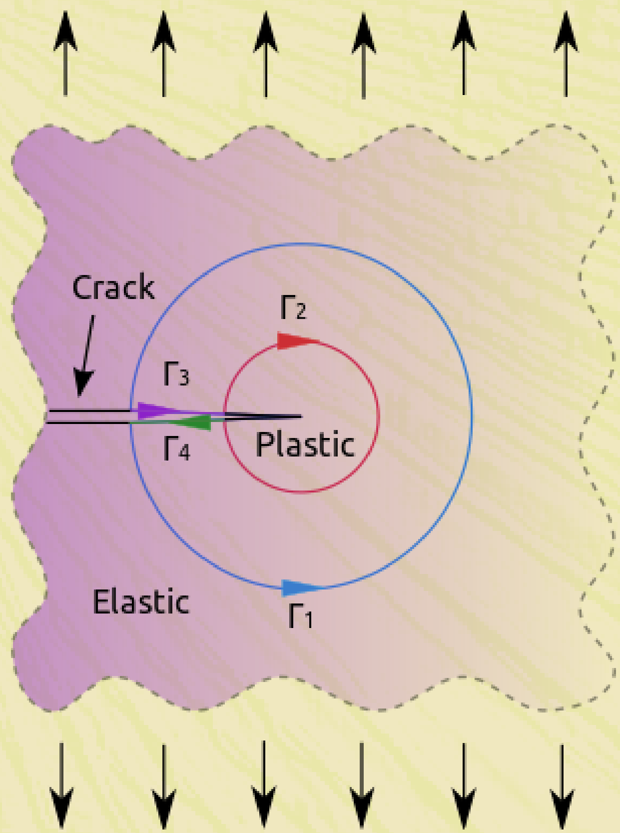
(simplectic integrator recommended)

Simulation - a thin film under tension

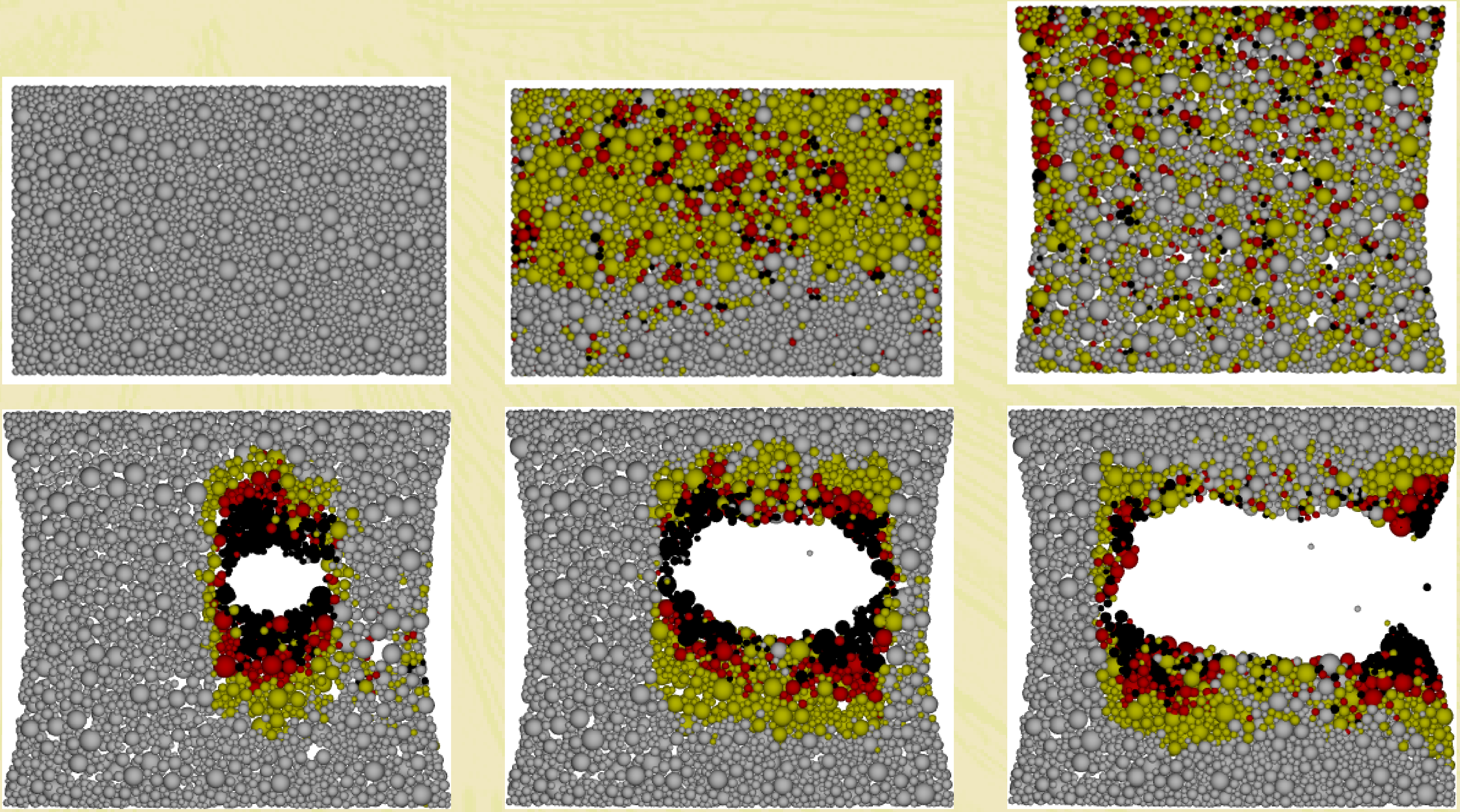


✦ harmonic atractive potential with constant separation limit

Fracture mechanics point of view

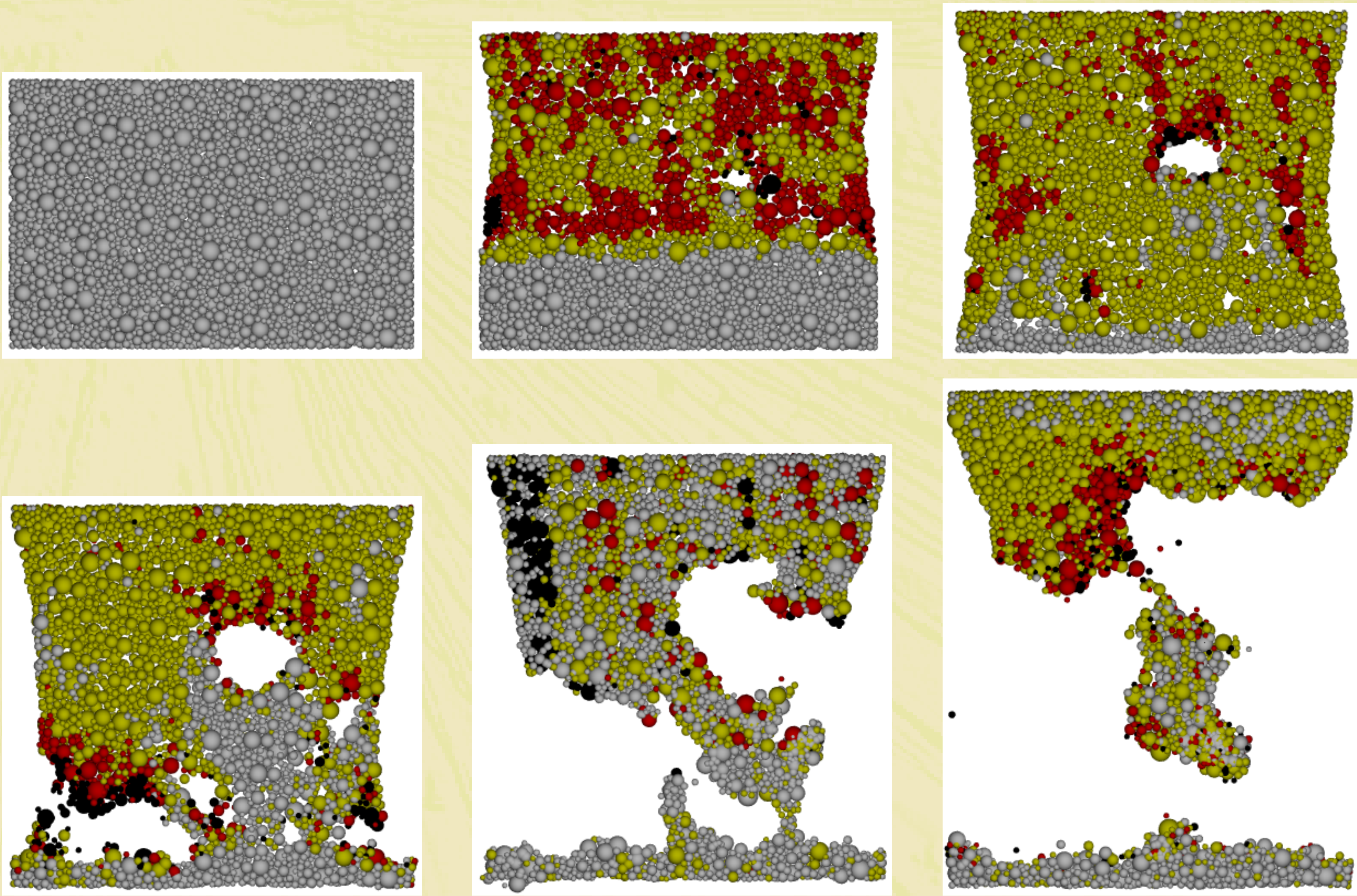


Simulations - slow loading

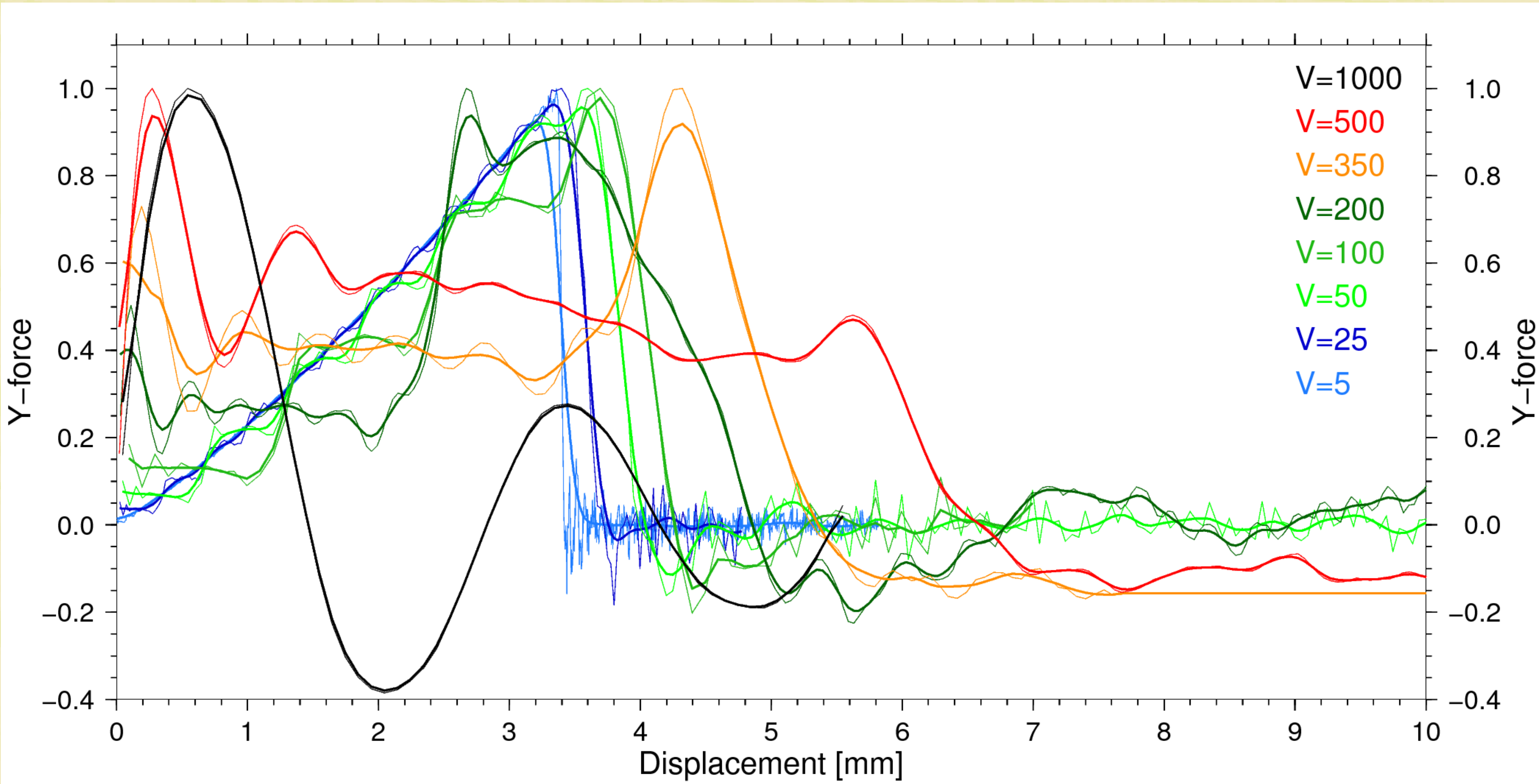


Particles velocity: high - low

Simulations - fast loading

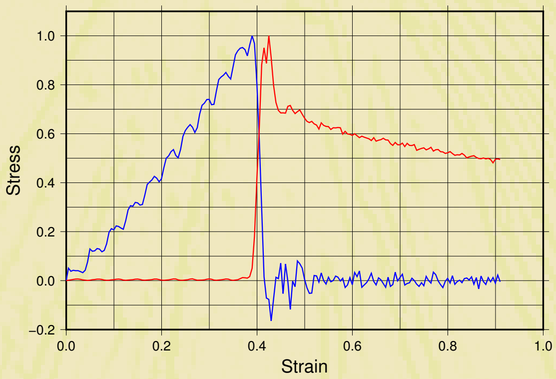


Simulations - loading speed effect

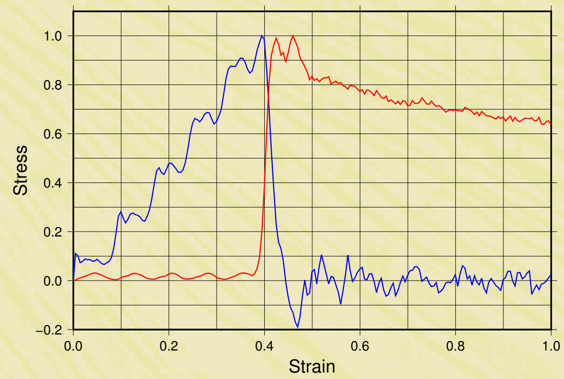


Simulations - loading speed effect cd.

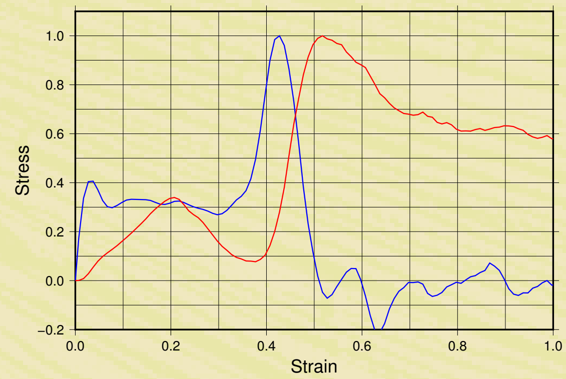
50 mm/s



100 mm/s

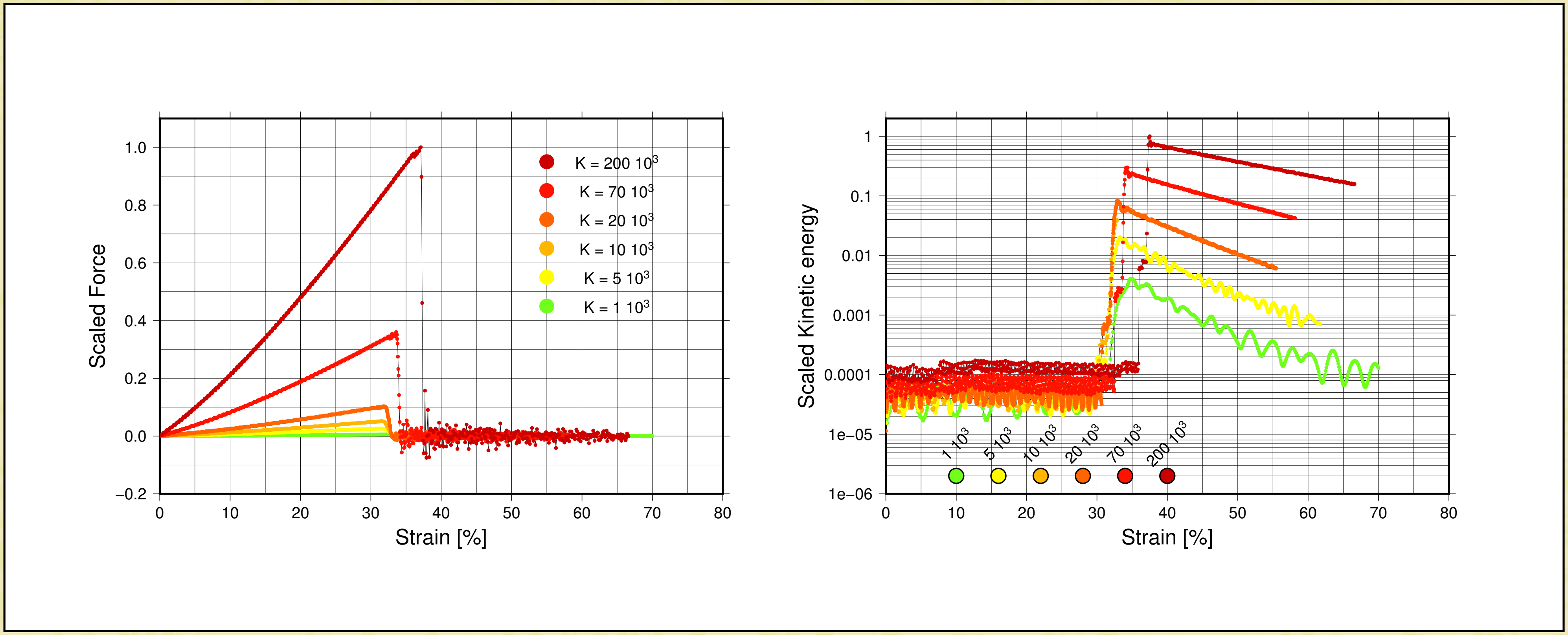


500 mm/s

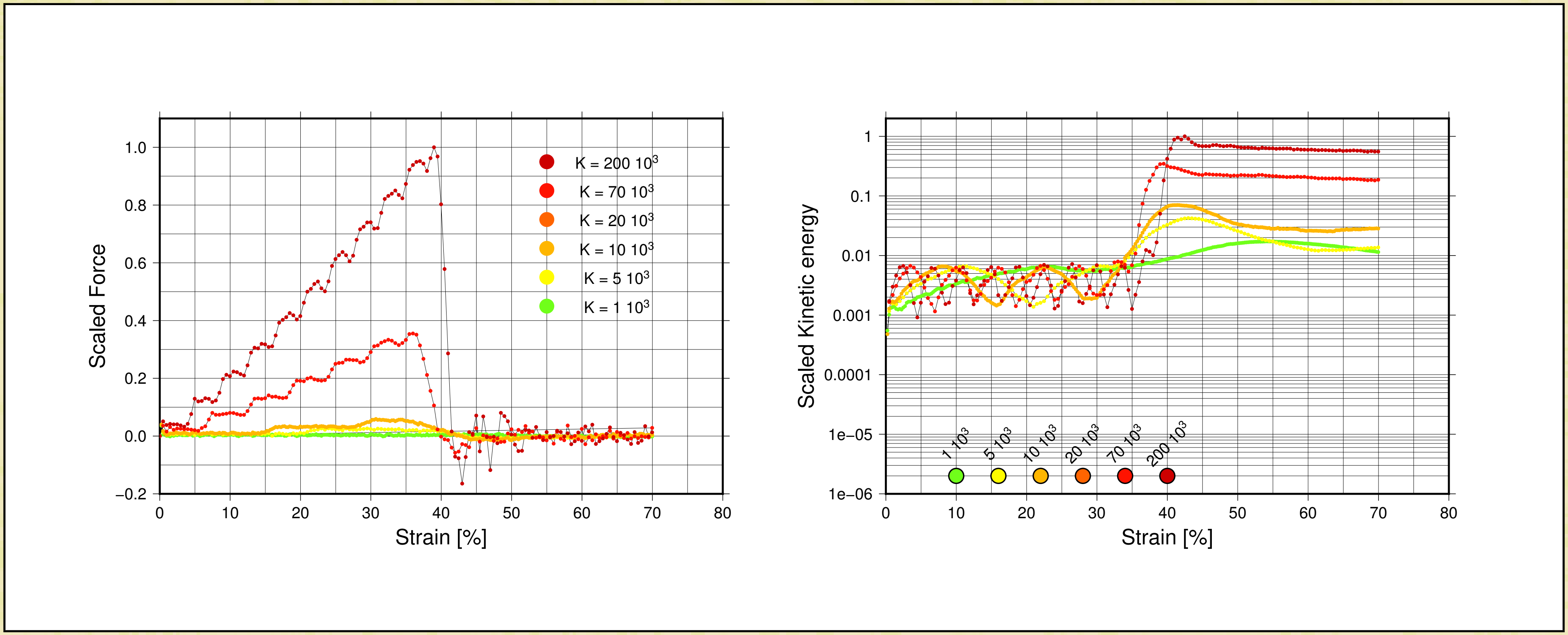


Nonlinear transfering of external load to the total kinetic energy of particles!

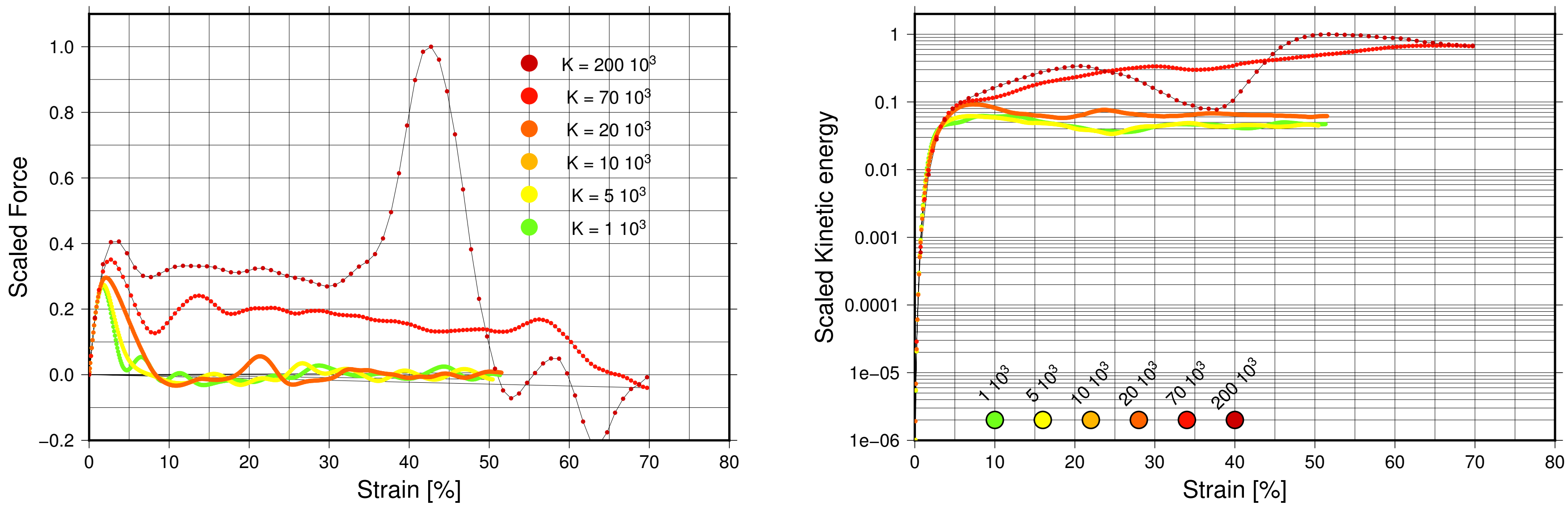
Simulations - inter-particle forces (V=5mm/s)



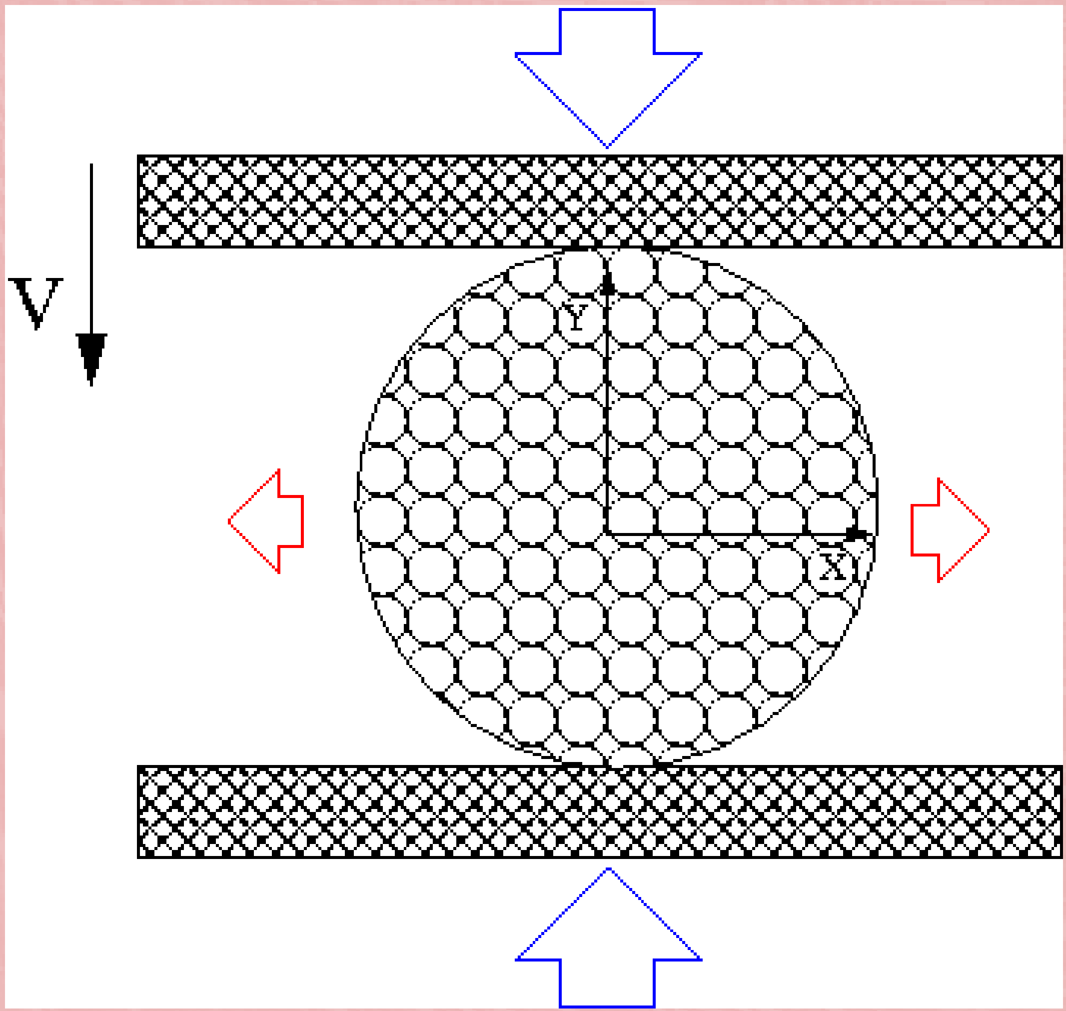
Simulations - inter-particle forces (V=50mm/s)



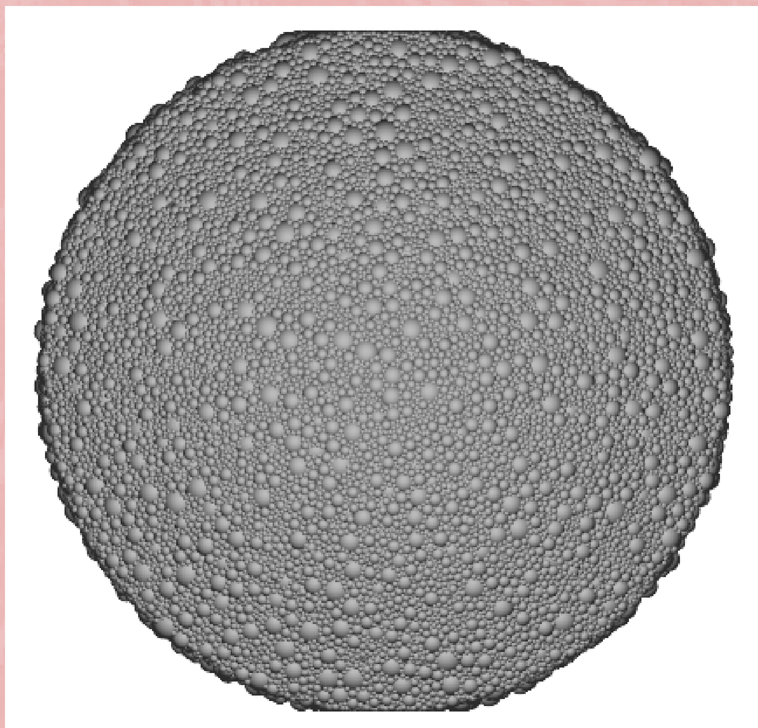
Simulations - inter-particle forces (V=500mm/s)

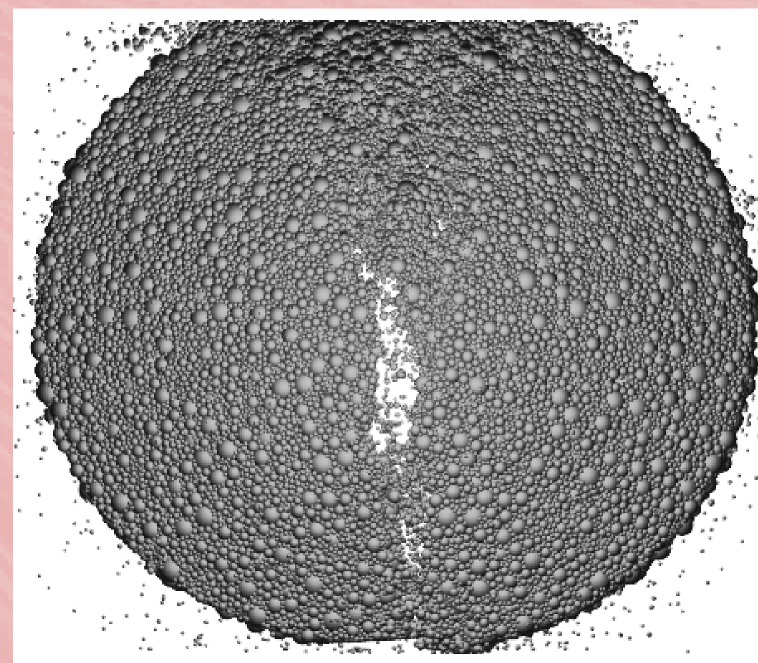


Simulation - The Brazilian test



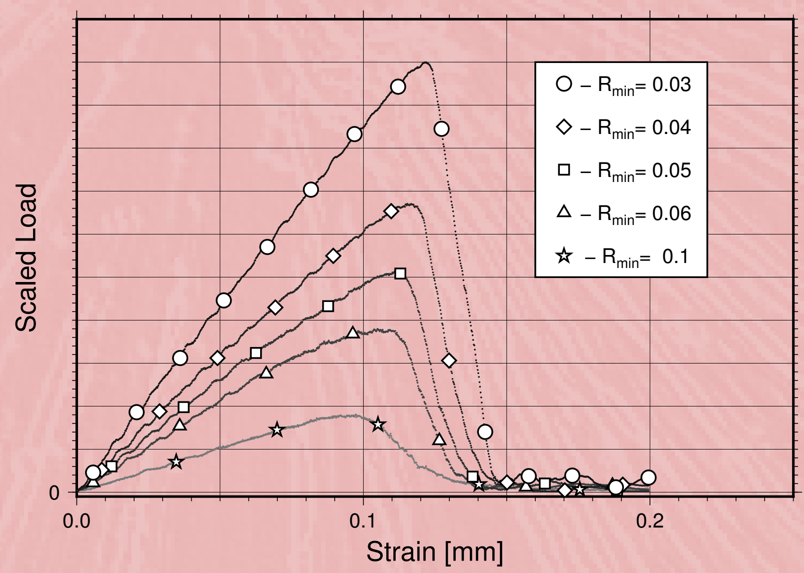
Simulations

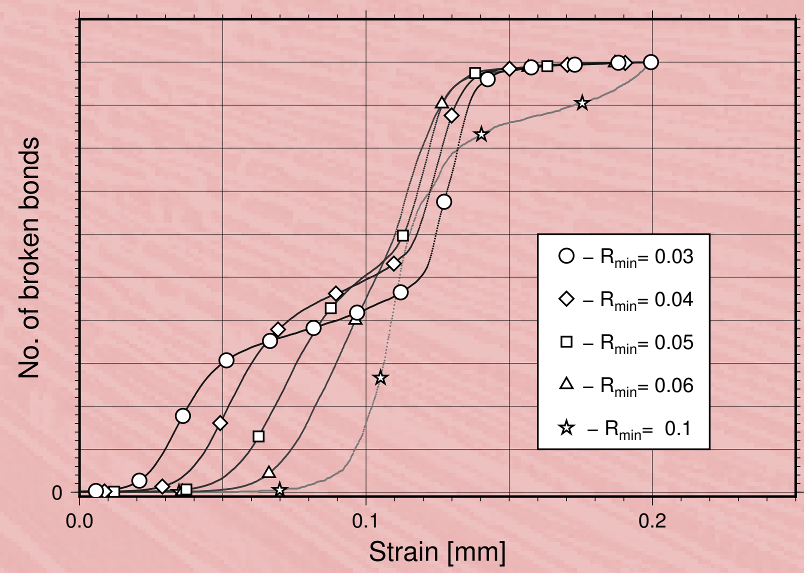




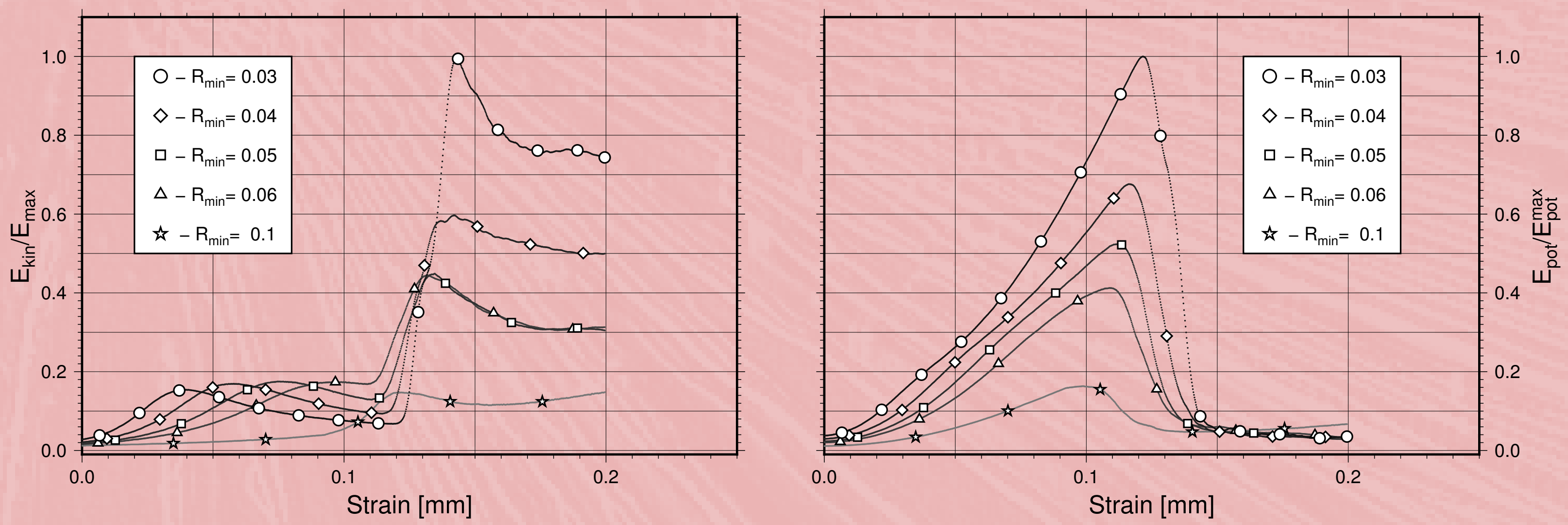
Particle size: $R_{max} = 0.2\text{mm}$, $R_{min} = 0.03 - 0.1\text{mm}$,

Simulations: load-strain

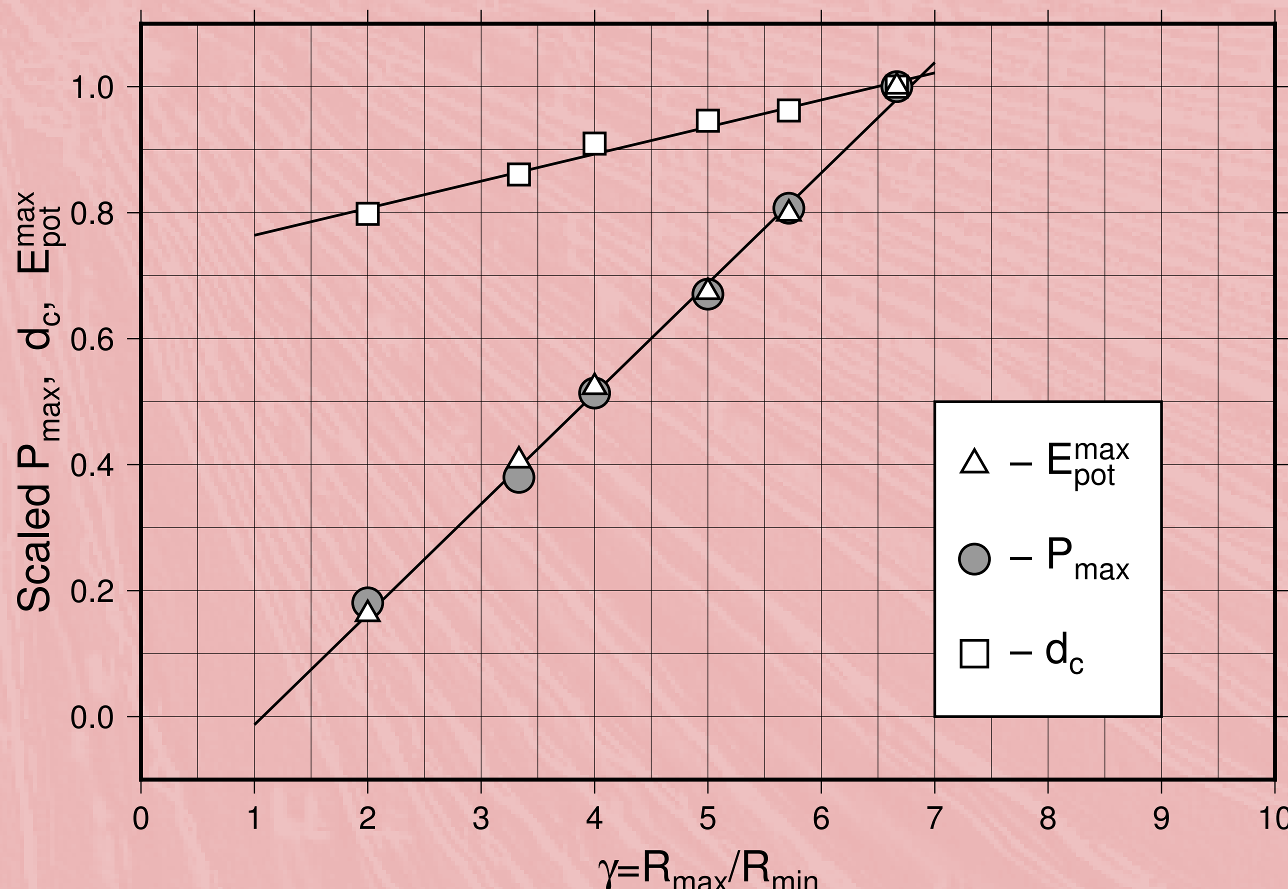




Simulations: kinetic an potential energy



Simulations: surprising linearity



Conclusions

Numerical simulation can provide meanigfull information on kinematics and dynamics of breaking processes.

END