

Discrete Element Simulation of Concrete Fracture and Crack Evolution

Birgit Beckmann, Kai Schicktanz, Manfred Curbach

SSCS Aix en Provence, May 29 – June 1, 2012



DRESDEN
concept
Exzellenz aus
Wissenschaft
und Kultur

Outline

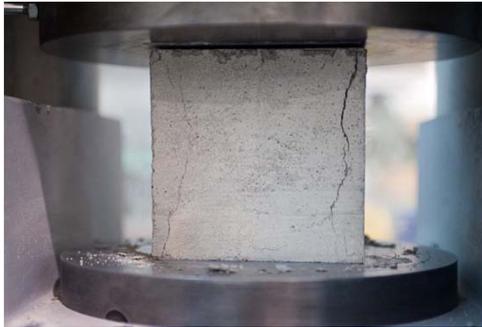
Motivation

Mechanical model

Results

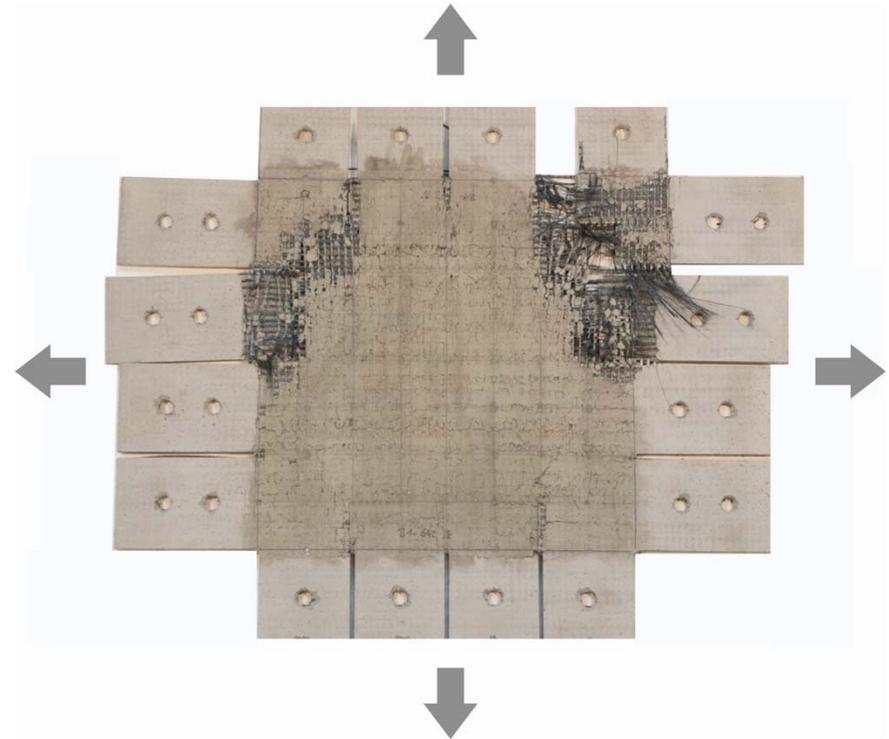
Concluding remarks

Fracture phenomena



Concrete specimens during compression test

Fracture phenomena



Textile Reinforced Concrete specimens during tensile test

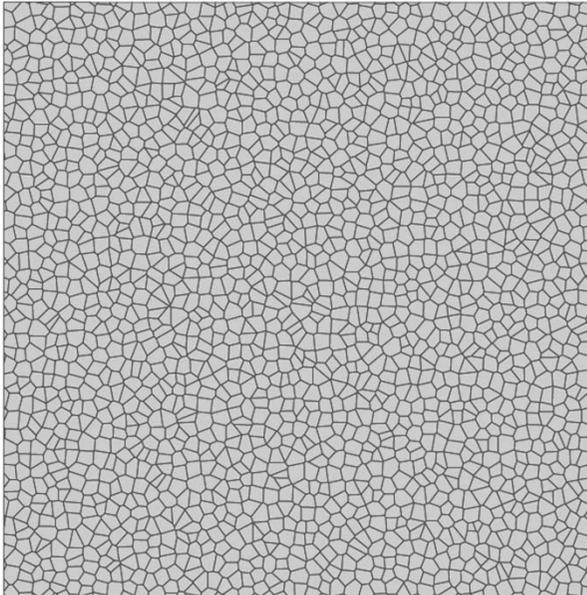
Discrete Element Simulation

- particles represent physical objects
- Cundall and Hart [1]: "model must
 - (a) allow finite displacements and rotations of discrete bodies, including complete detachment, and
 - (b) recognize new contacts automatically as the calculation progresses"
- particle contact detection
- discontinuities are inherent part of the simulation
- no "crack elements", interaction of separating particles → crack pattern.
- Plassiard and Donzé [2]: explicitly discrete nature, description of slipping surfaces and collapse processes

[1] Cundall, P. A.; Hart, R. D.: Numerical Modelling of Discontinua Engineering Computations, 1992, 9, 101-113

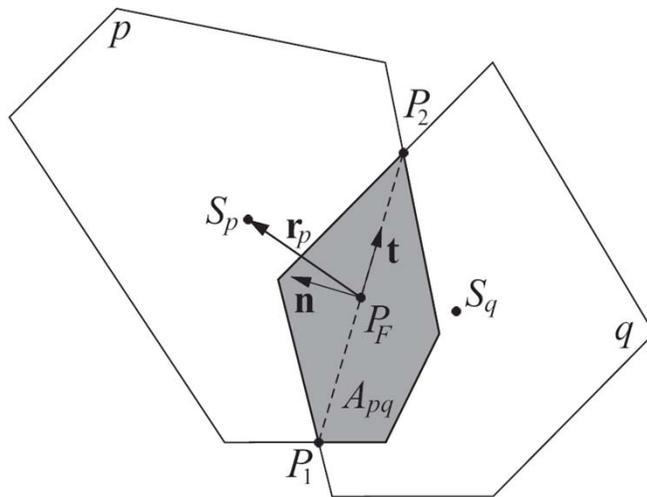
[2] Plassiard, J.; Donze, F.: Rockfall Impact Parameters on Embankments: A Discrete Element Method Analysis Structural Engineering International, 2009, 19, 333-341

Particle ensemble



- discrete, kinematically independent particles
- Newton's second law;
- force from particle interaction (mass, position, velocity)
- particle interaction: contact approach
- arbitrarily polygonal particle geometry
- equation of motion, integration for each particle (system of ODEs)

Particle interaction – contact approach



Kohring et al. [3], Tillemans and Hermann [4], D'Addetta et al. [5]:

overlap area \rightarrow repulsing force

$$\mathbf{F}_{pq}^c \propto A_{pq}$$

$$\mathbf{F}_{npq}^c = \frac{1}{\ell} k_p A_{pq} \mathbf{n} - m_{eff} \gamma_n v_{nrel} \mathbf{n}$$

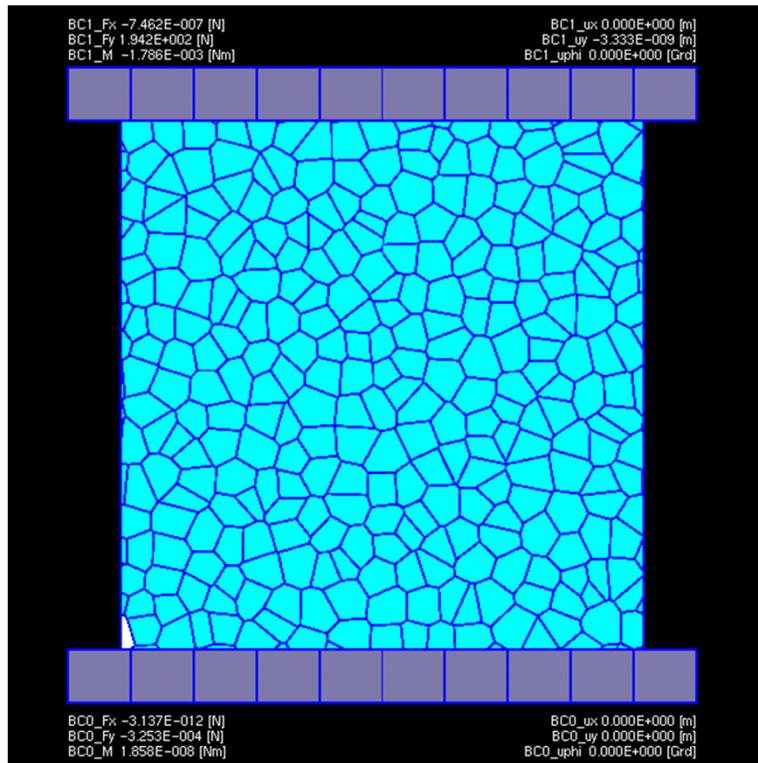
$$\mathbf{F}_{tpq}^c = -(v_{trel}) \min \left(m_{eff} \gamma_t |v_{trel}|, \mu \left| \mathbf{F}_{npq}^c \right| \right) \mathbf{t}$$

[3] Kohring, G. A.; Melin, S.; Puhl, H.; Tillemans, H.; Vermöhlen, W.: Computer simulations of critical, nonstationary granular flow through a hopper *Computer Methods in Applied Mechanics and Engineering*, 1995, 124, 273-281

[4] Tillemans, H.; Herrmann, H. J.: Simulating deformations of granular solids under shear *Physica A: Statistical and Theoretical Physics*, 1995, 217, 261-288

[5] D'Addetta, G. A.; Kun, F.; Ramm, E. On the application of a discrete model to the fracture process of cohesive granular materials *Granular Matter*, 2002, 4, 77-90

Particle generation

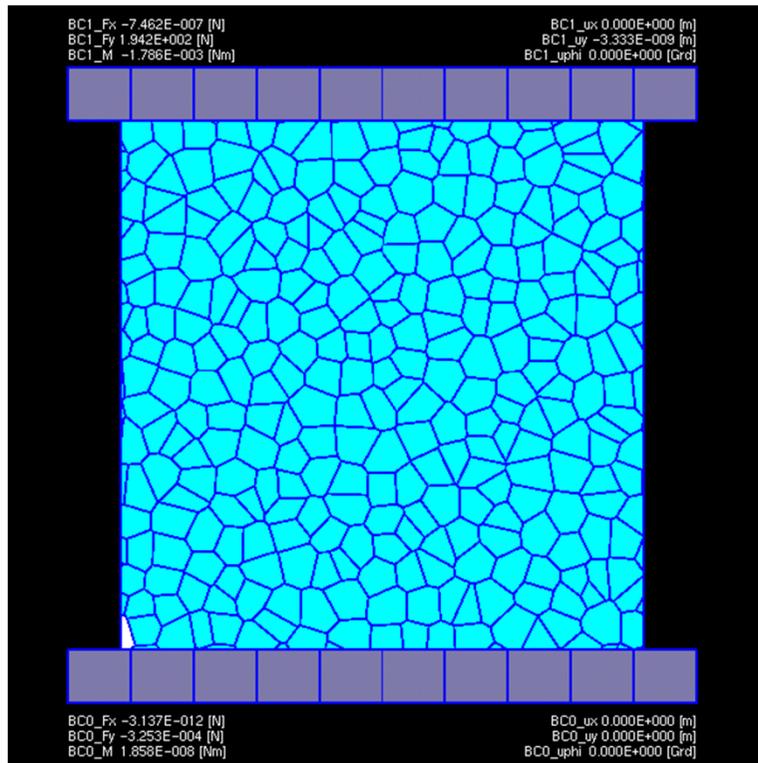


- polygons
- convex particles
- similar size, arbitrarily polygonal shape

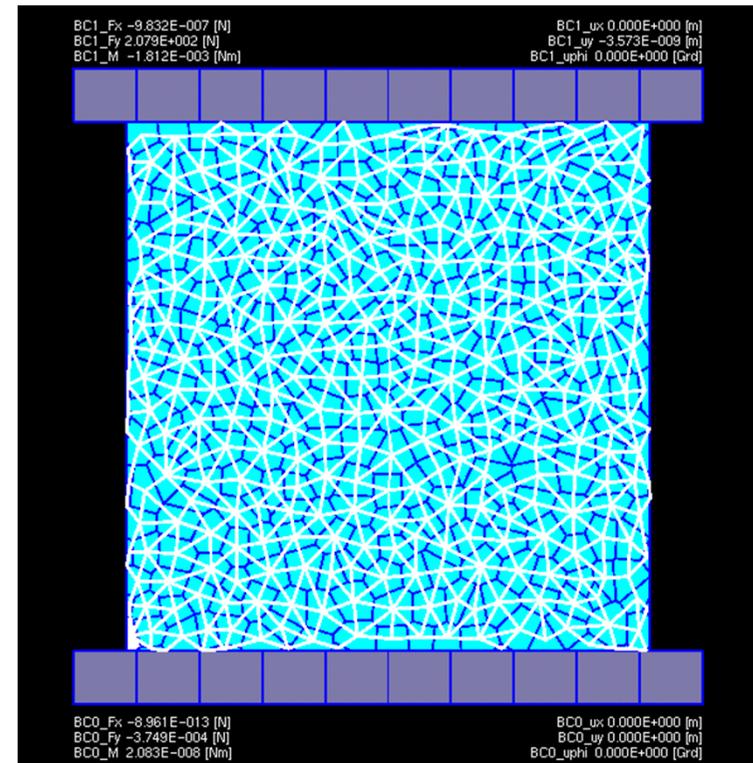
VRL Voronoi tessellation [6]

[6] Moukarzel, C.; Herrmann, H. J.: A vectorizable random lattice J. Stat. Phys., 1992, 68, 911-923

Particle generation



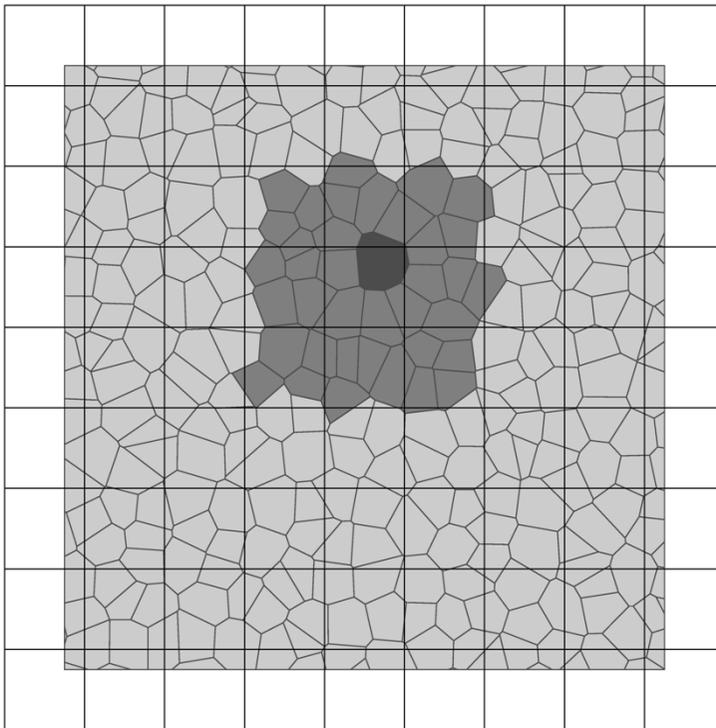
VRL Voronoi tessellation [6]



Delaunay triangulation

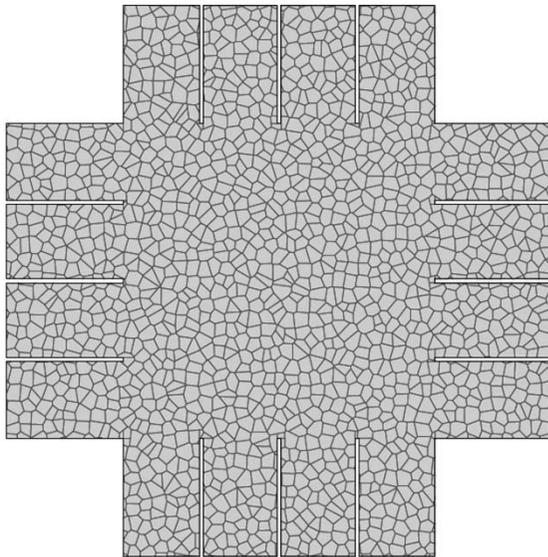
[6] Moukarzel, C.; Herrmann, H. J.: A vectorizable random lattice J. Stat. Phys., 1992, 68, 911-923

Contact detection

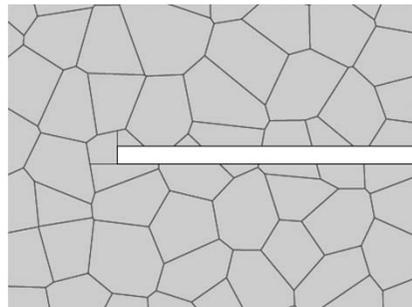


Linked Cells

Convex particles

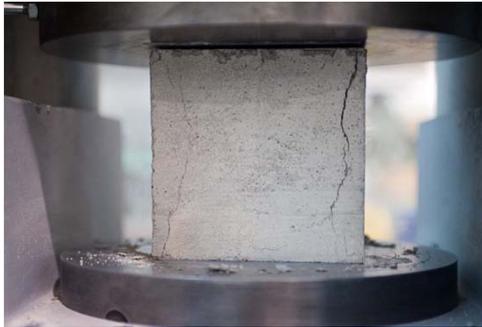


Nonconvex concrete body



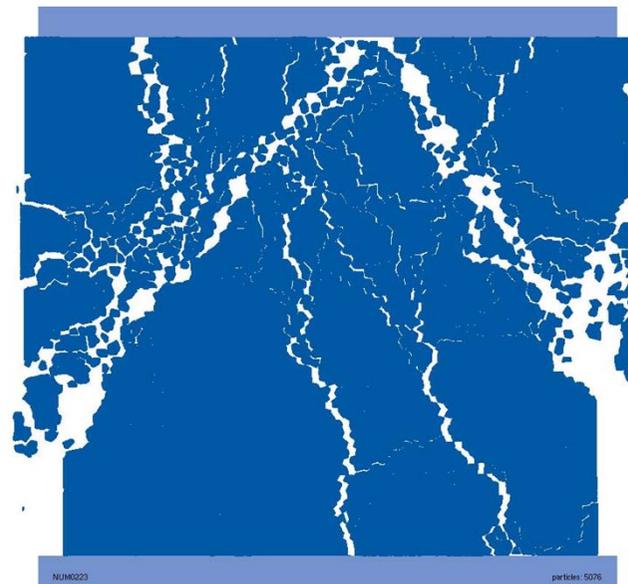
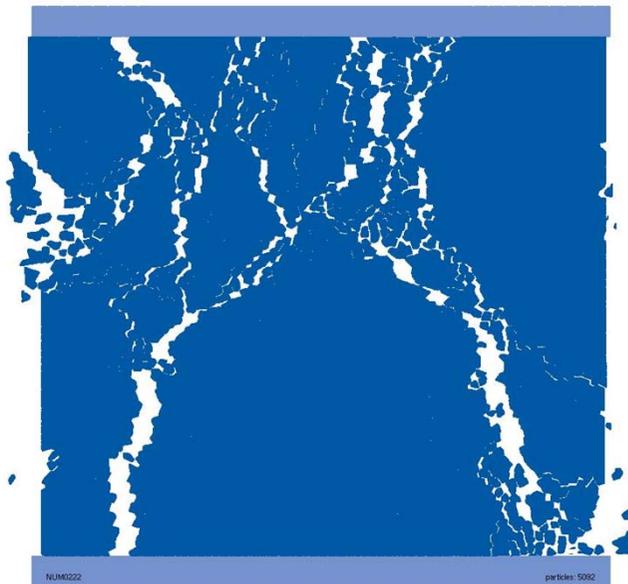
Subparticles

Crack pattern in laboratory test



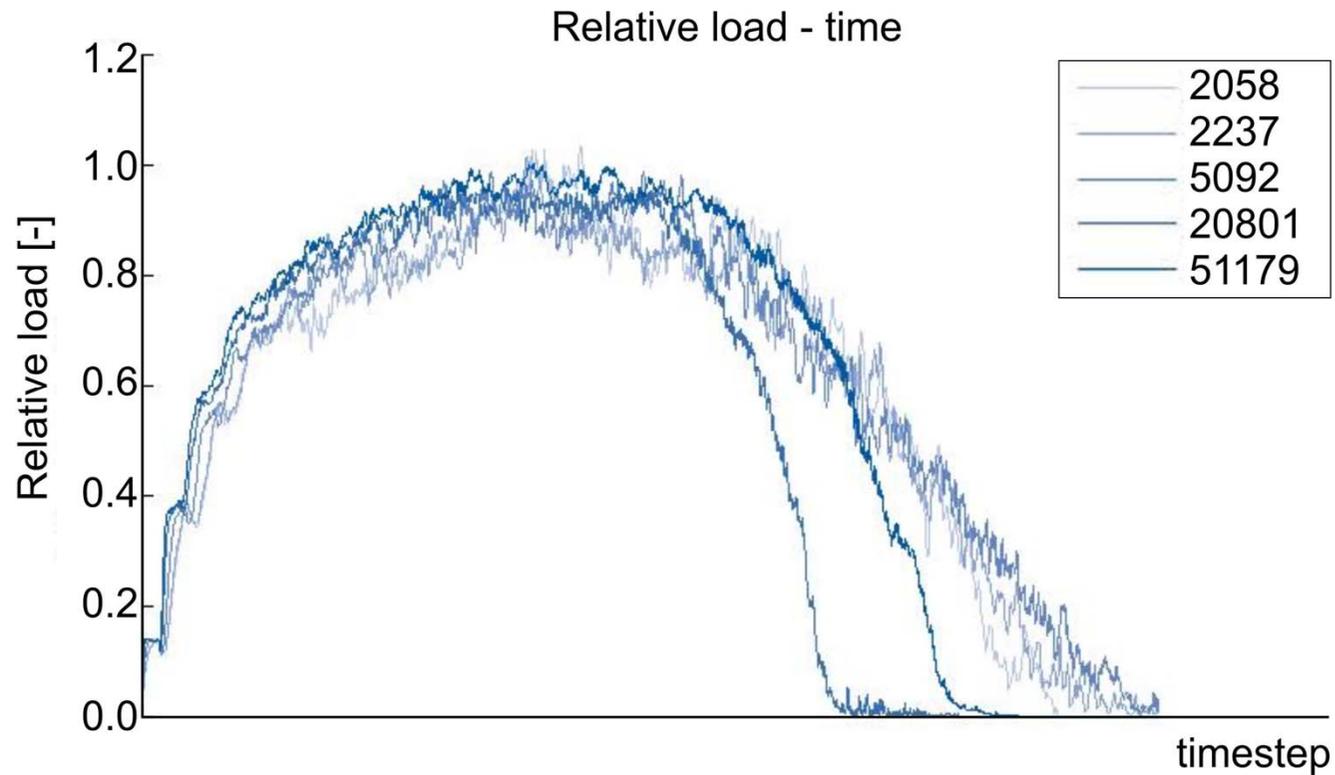
Concrete specimens during compression test

Crack pattern in simulation

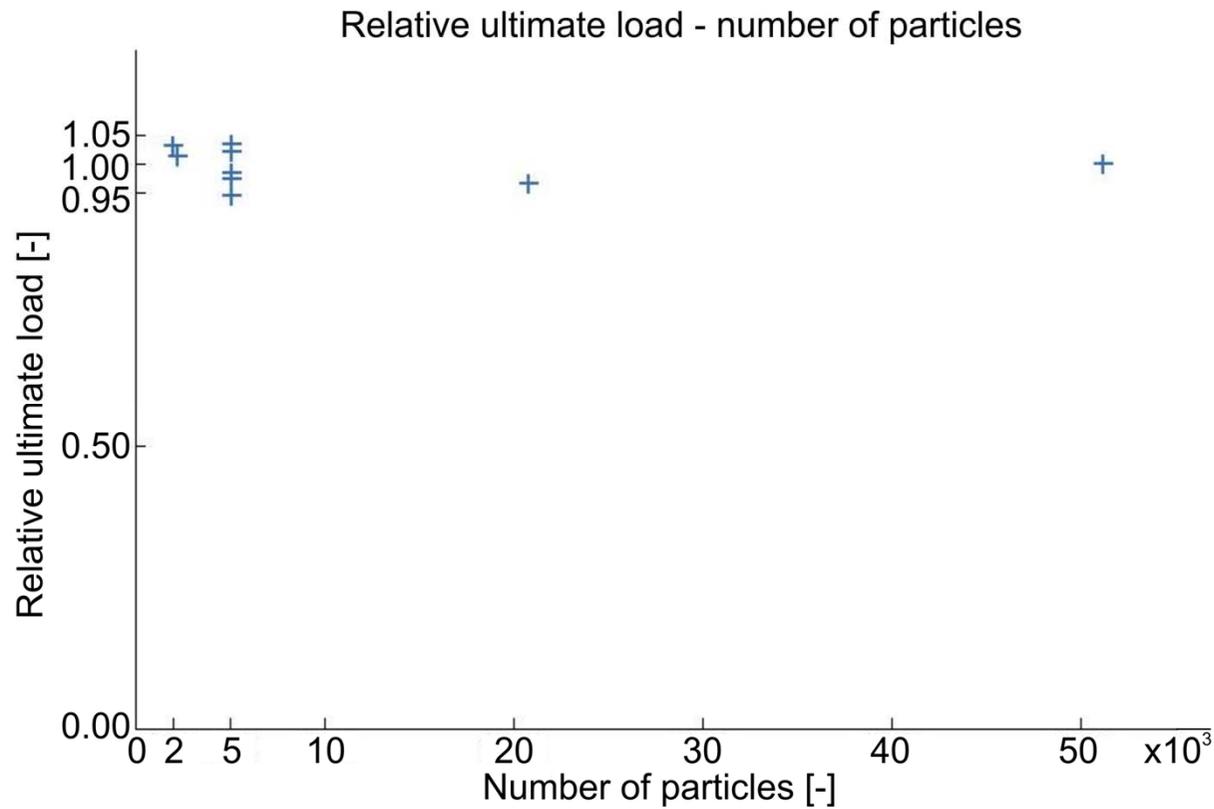


- phenomenologically similar
- different crack positions, different spalling

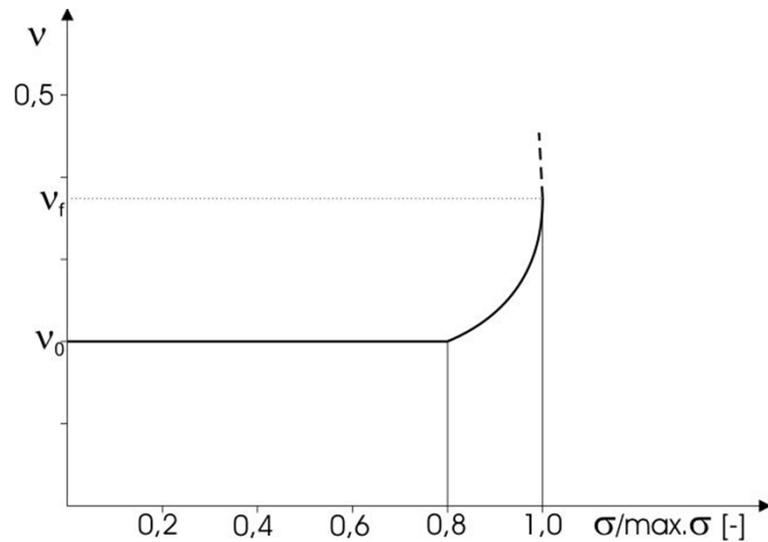
Independent: ultimate load, particle number



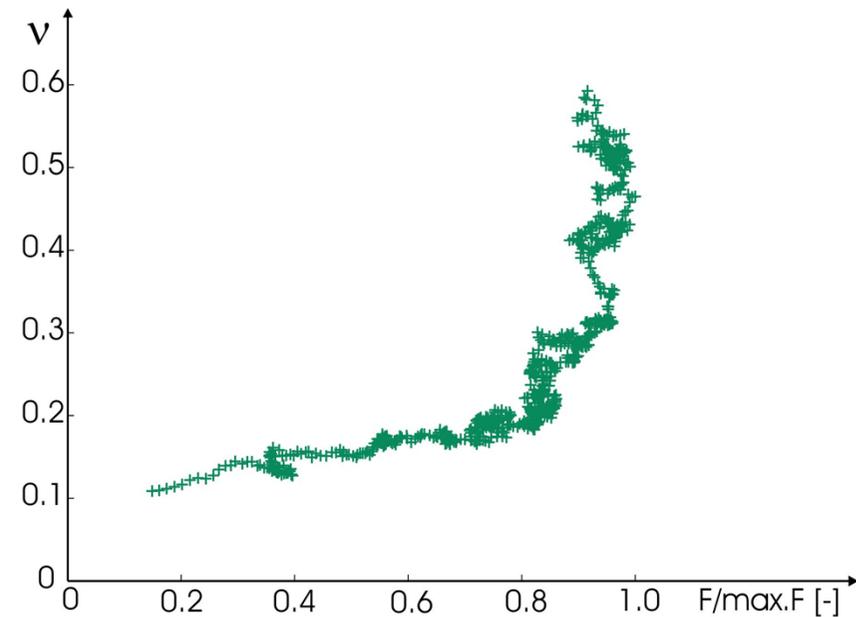
Independent: ultimate load, particle number



Ratio of longitudinal and lateral strain



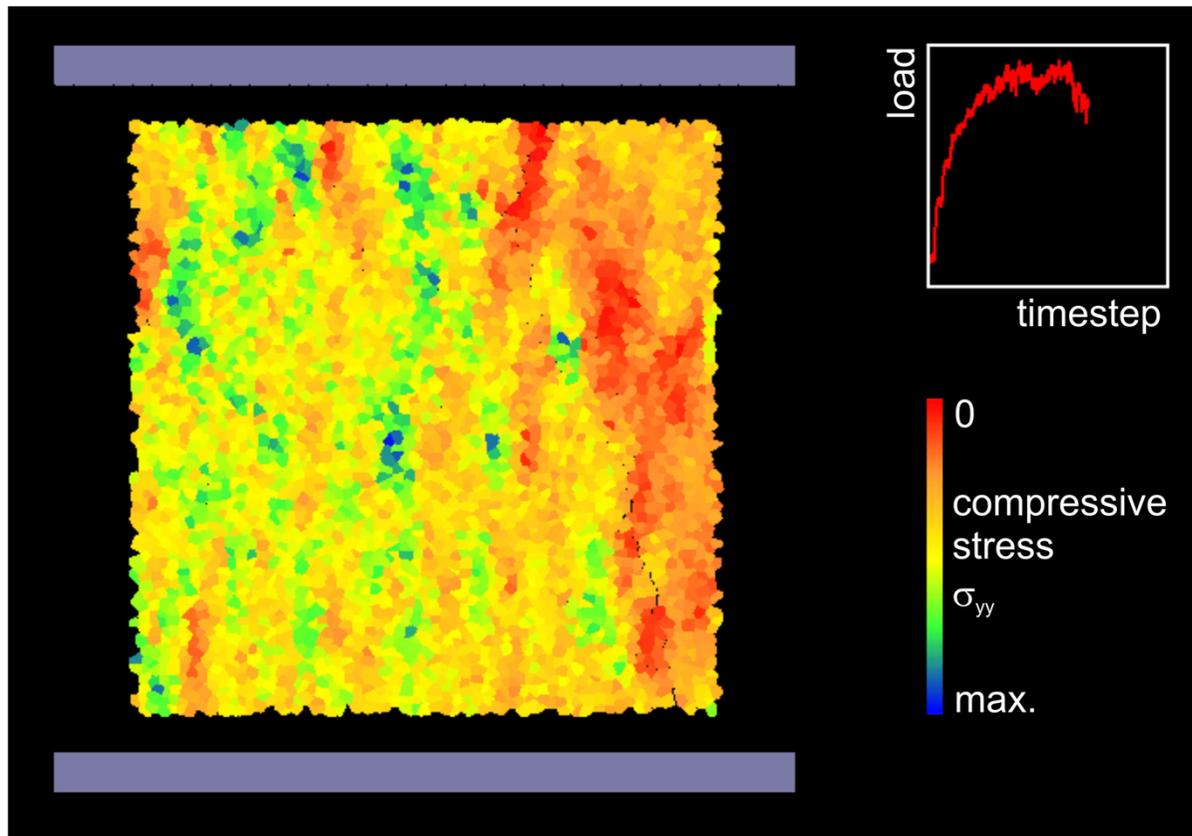
Ratio according to Schlüter [7]



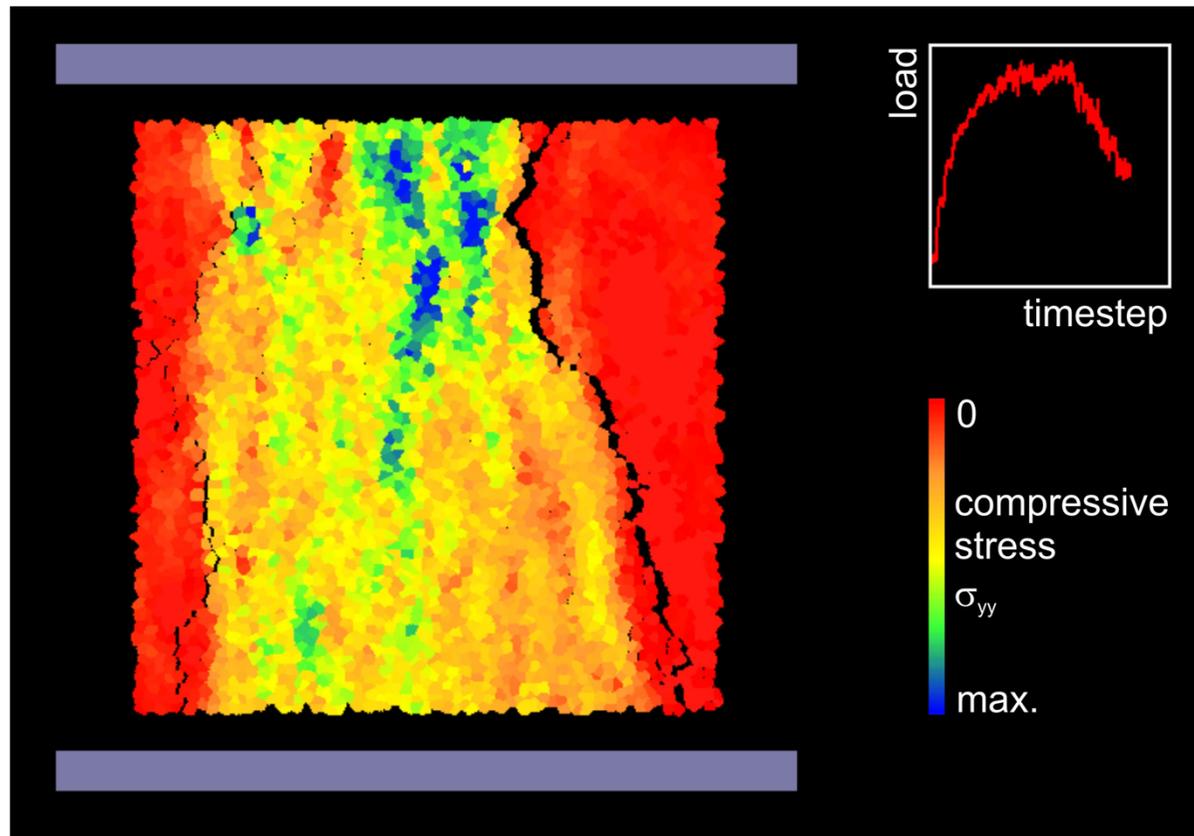
Ratio in the simulation

[7] Schlüter, F. Dicke Stahlbetonplatten unter stoßartiger Belastung – Flugzeugabsturz – Universität Fridericana zu Karlsruhe (TH), 1987

Crack evolution and compressive stress



Crack evolution and compressive stress



Concluding remarks

- crack pattern: laboratory test, simulation
- simulated break load independent of particle number
- variation of break load ~5%
- ratio of longitudinal and lateral strain: strong increase above 80% in load intensity
- discontinuity inherent property of the method
- no "crack elements"
- macroscopic effects emerge due to interaction of particles
- DEM simulation, failure process and crack evolution

Discrete Element Simulation of Concrete Fracture and Crack Evolution

Birgit Beckmann, Kai Schicktanz, Manfred Curbach

SSCS Aix en Provence, May 29 – June 1, 2012