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Numerical Simulation with Finite Element Material Point Methods for Problems of Extreme Deformation

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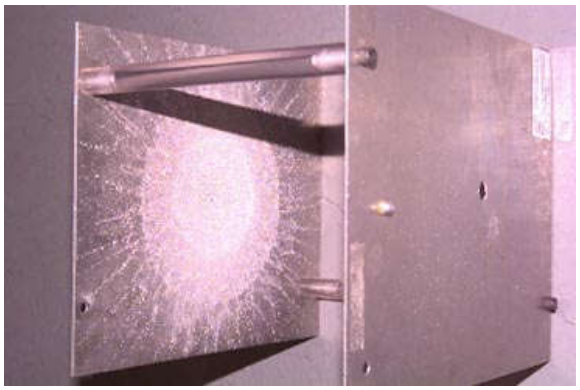
Outline

- **Introduction**
- Material Point Method
- Finite Element Material Point Methods
- Applications
- Concluding remarks

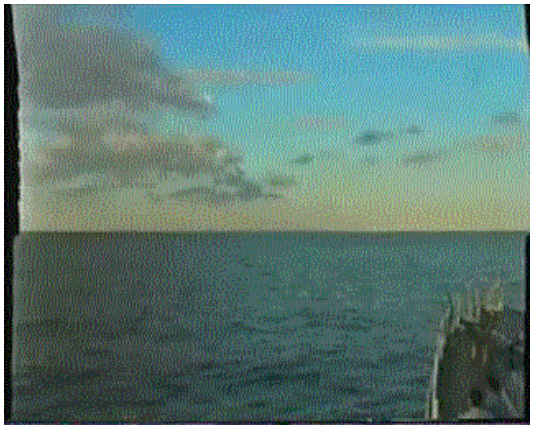
Introduction

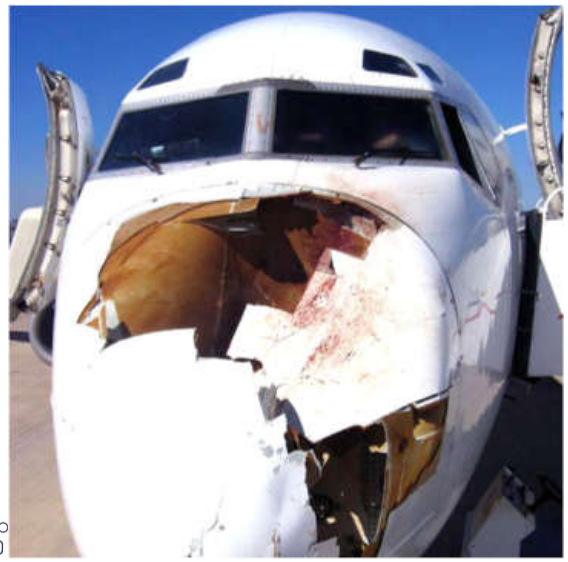
Extreme deformation problems

- Hyper velocity impact
- Impact and penetration
- Blast loading
- Sloshing
- Metal cutting
- Friction stir welding
- Explosive welding









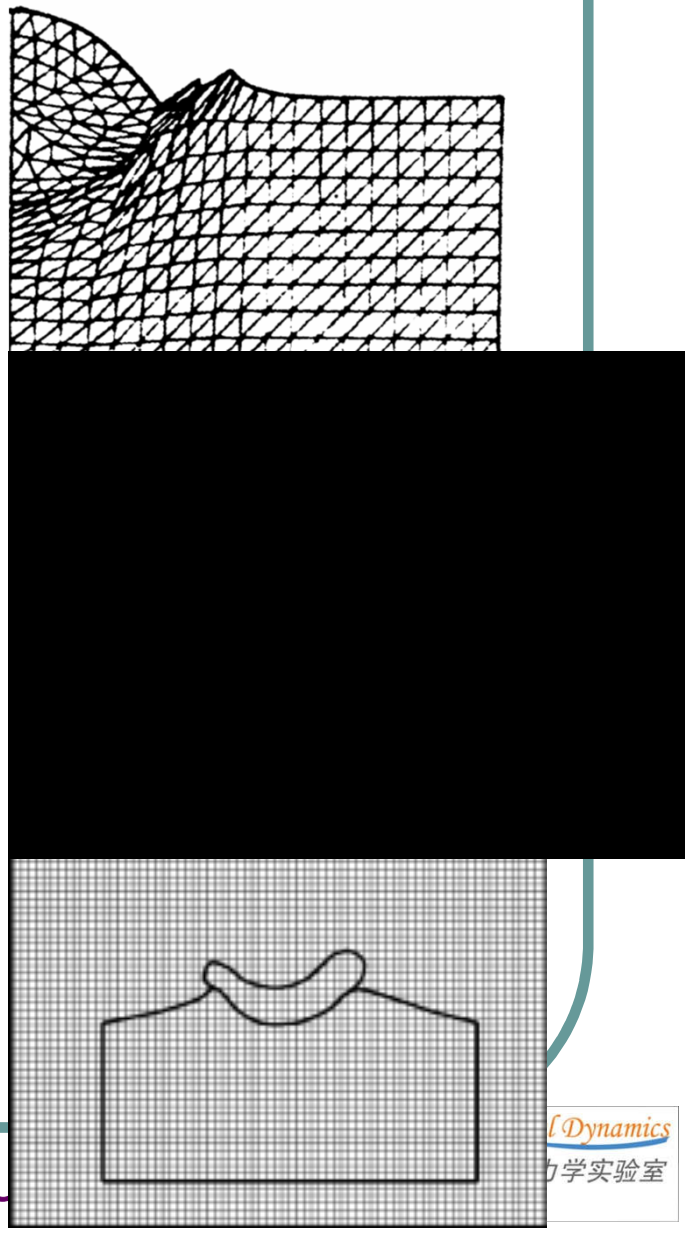




Introduction

Numerical challenges

- Highly nonlinear
  - Geometrical nonlinearity
  - Material nonlinearity
  - Boundary condition nonlinearity
- Localized extreme deformation
- Lagrangian method
  - Mesh distortion (accuracy, time step)
  - Fragmentation (discontinuity)
  - Nonphysical erosion algorithm
- Eulerian method
  - Material interface
  - History dependent material
  - Diffusion and dispersion

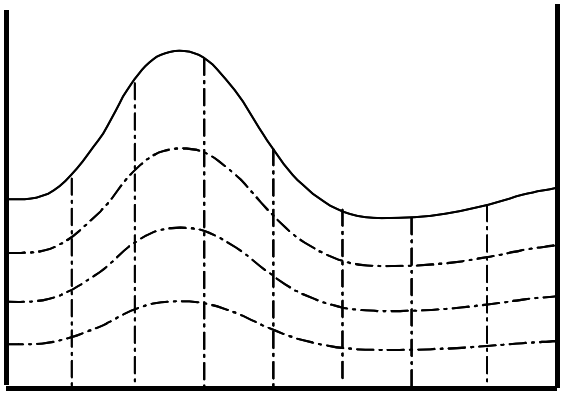


Introduction

Numerical challenges

- Hybrid Lagrangian-Eulerian methods
  - Arbitrary Lagrangian Eulerian (ALE)
  - **Particle In Cell (PIC)** ⟶ **FLIP** (Fluid-Implicit-Particle)
- Meshfree methods
  - **SPH**
  - EFG
  - RKPM
  - MLPG
  - … …

MPM (Material Point Method)

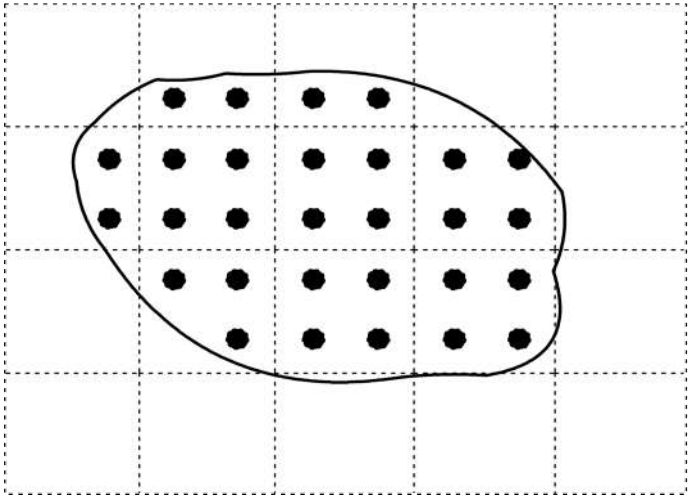


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Material Point Method

- Material Point Method (Sulsky, Chen et. al. 1994)
  - An extension of the FLIP PIC method to solid mechanics
  - Discretizes a material domain by particles moving through an Eulerian background mesh
  - Fully Lagrangian particle method
    - Particles carry all state variables
    - Grid carries no permanent information



Material Point Method

Basic Formulation

- In each time step

FEM

- Grid nodal momentum equations

$$\dot{p}_{iI}^{k} = f_{iI}^{k} = f_{iI}^{k,\text{ext}} + f_{iI}^{k,\text{int}}$$

$$m_I^k = \sum_p m_p N_{Ip} \qquad p_{iI}^k = \sum_p m_p v_{ip}^k N_{Ip}$$

$$f_{iI}^{k,\text{int}} = -\int_\Omega N_{I,j}\sigma_{ij}\,\mathrm{d}V$$

Particle quadrature

$$f_{iI}^{k,\text{int}} = -\sum_p N_{Ip,j}\sigma_{ijp}V_p$$

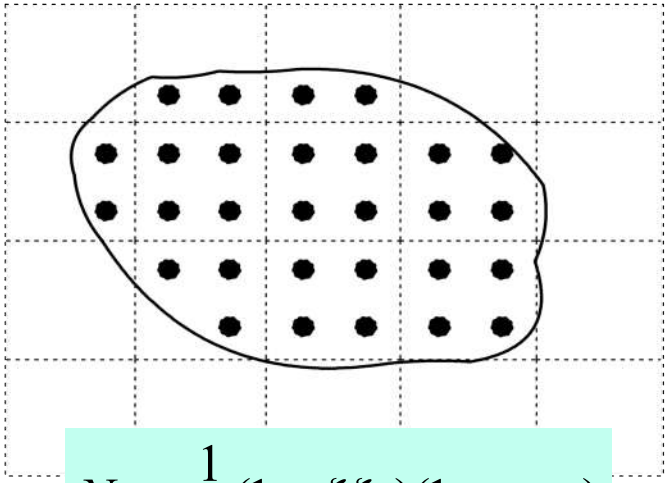
- Particle update

$$v_{ip}^{k+1/2} = v_{ip}^k + \sum_I \frac{f_{iI}^k}{m_I^k} N_{Ip}\Delta t$$

$$x_{ip}^{k+1} = x_{ip}^k + \sum_I \frac{p_{iI}^{k+1/2}}{m_I^k} N_{Ip}\Delta t$$

- The deformed grid is discarded, and a new regular grid is used

Remesh



$$N_g = \frac{1}{4}(1+\xi\xi_g)(1+\eta\eta_g)$$

MPM is a FEM-based particle method

Material Point Method

- Combines the advantages of Lagrangian and Eulerian methods
  - History-dependent constitutive models
  - Free surfaces or multiple materials
  - No mesh distortion and element entanglement
  - Promising in modeling **extremely large deformation** and material discontinuities
- Compared with FEM
  - Take use of both grid and particle data ⟹ ***Efficient implementation***
  - Particle quadrature instead of Gauss quadrature
  - Less accurate, less efficient, and more storage usage for **small deformation problem** ⟹ ***Combined with other methods***

Combined with Finite Element Method
Combined with Finite Difference Method
Combined with Molecular Dynamics
Combined with Dissipative Particle Dynamics

- 张雄,廉艳平,刘岩,周旭. 物质点法. 清华大学出版社, 2013.9
- 张雄, 陈震, 刘岩. ***The Material Point Method*** - A Continuum-Based Particle Method for Extreme Loading Case. Published by Elsevier, 2016.11.

Material Point Method

MPM3D – 3D explicit MPM code

- MPM3D solver
  - Algorithm
    - MPM / GIMP (USF, USL & MUSL); iMPM
    - FEM / FEM-MPM
    - FDM / FDM-MPM
  - Material models
    - Elasticity, plasticity (hardening, temperature, strain rate)
    - Fluid, High explosive
    - Metal, Concrete, Ceramic, rubber, Foam, Soil …
  - Equation of states
    - Solid
    - Fluid
    - High explosive
  - Failure models
    - Hydrodynamic tensile failure; Effective plastic strain
    - Principal stress failure; Principal strain failure

- **MPM3D-F90:** Open source version
- **MPM3D:** Free trial until 12-31-2016
  http://mpm3d.comdyn.cn

- 张雄,廉艳平,刘岩,周旭. 物质点法. 清华大学出版社, 2013.9
- 张雄, 陈震, 刘岩. ***The Material Point Method*** - A Continuum-Based Particle Method for Extreme Loading Case. Published by Elsevier, 2016.11.

- Graphical User Interface (GUI)
  - Preprocessor
    - Create 3D solid models & Particle discretization
    - Setup solution parameters
    - Generate input data for solver
  - Solution process monitor
    - Call MPM3D solver to solve the model
    - Real Time Monitoring (Energy, momentum, animation)
    - Interactive steering (Pause/Resume/Restart/Stop)
    - Auto-testing
  - Postprocessor
    - Solver ➔ ParaView (http://www.paraview.org)
  - Cross platform (Windows, Linux, Mac OS X)

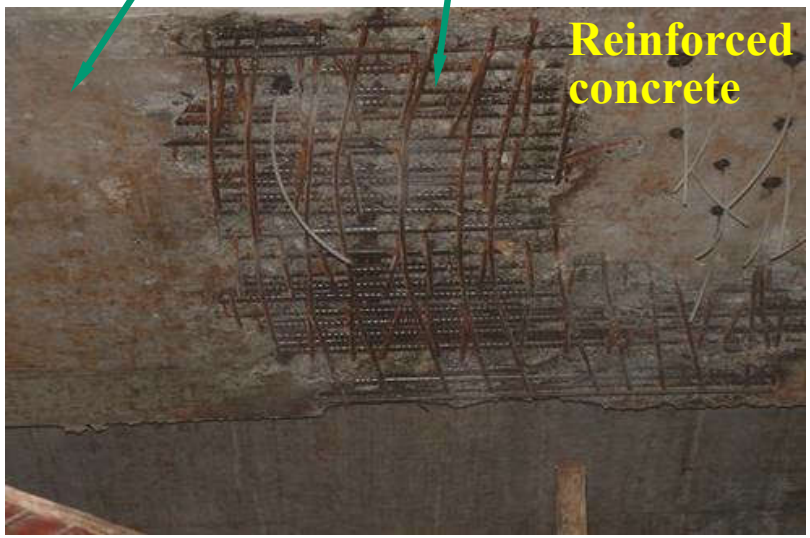
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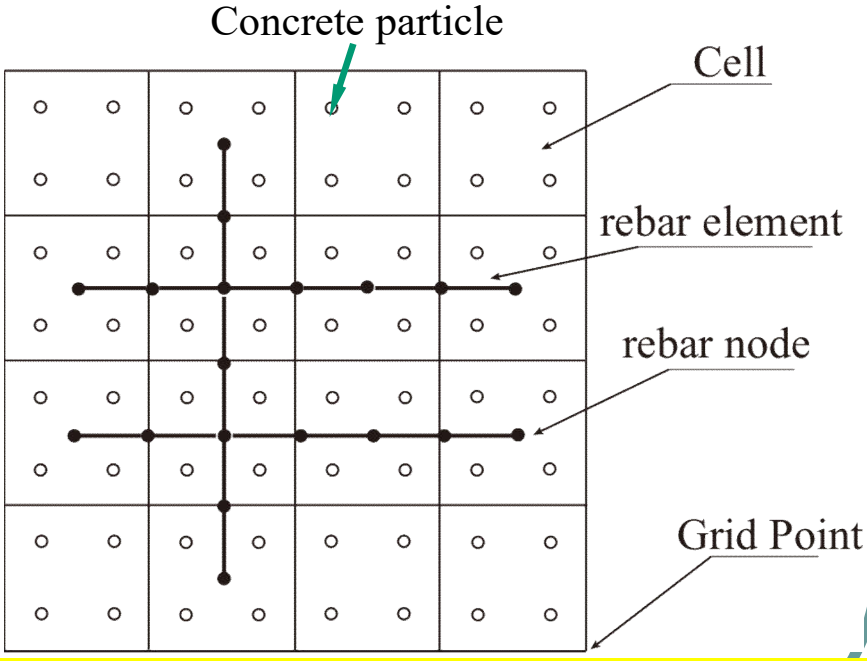
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Finite Element Material Point Methods

Hybrid FE-MP method

- Plain concrete is discretized into particles
- Rebars are discretized into bar elements (rebar elements)
  - Rebar nodes carry kinematic variables
  - Rebar elements carry history variables
- All the rebar nodes and particles move in the same single-valued velocity field



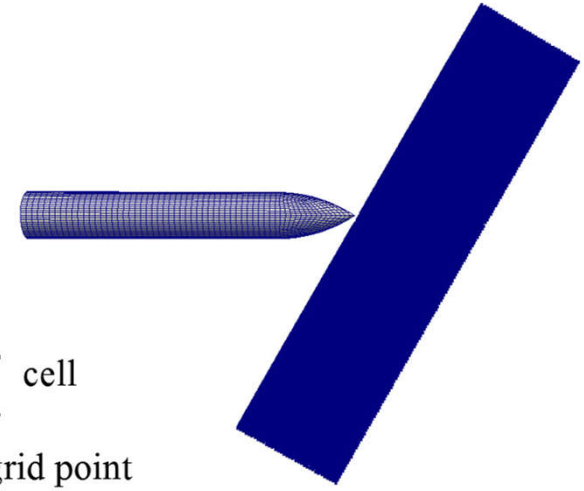


YP Lian, X Zhang, et al. A FEMP method and its application in modeling dynamic response of reinforced concrete subjected to impact loading. ***Computer Methods in Applied Mechanics & Engineering***, 200(17-20): 1659-1670, 2011.

Finite Element Material Point Methods

Coupled FE-MP method



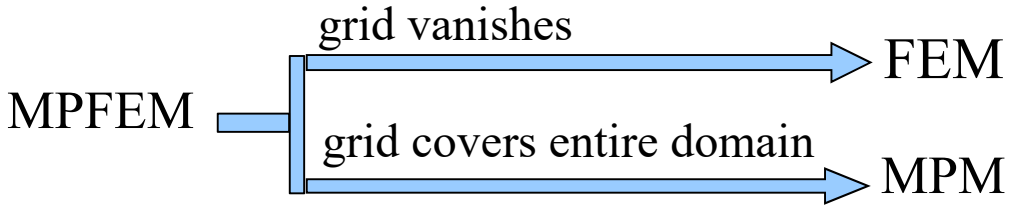


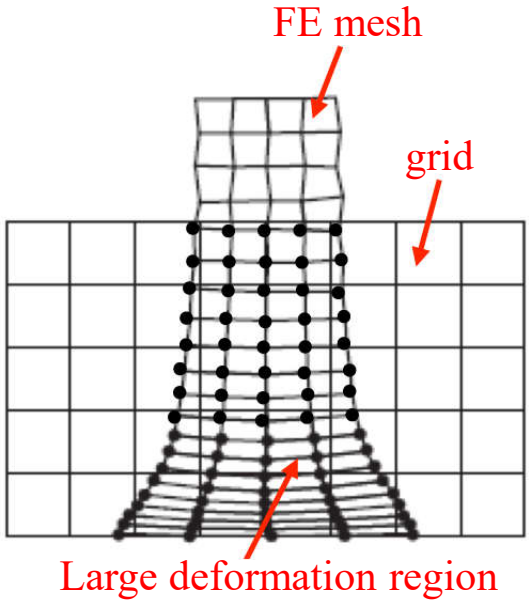
- Discretize different bodies by FEM and MPM, respectively
- Interaction between bodies is handled by ***contact methods***

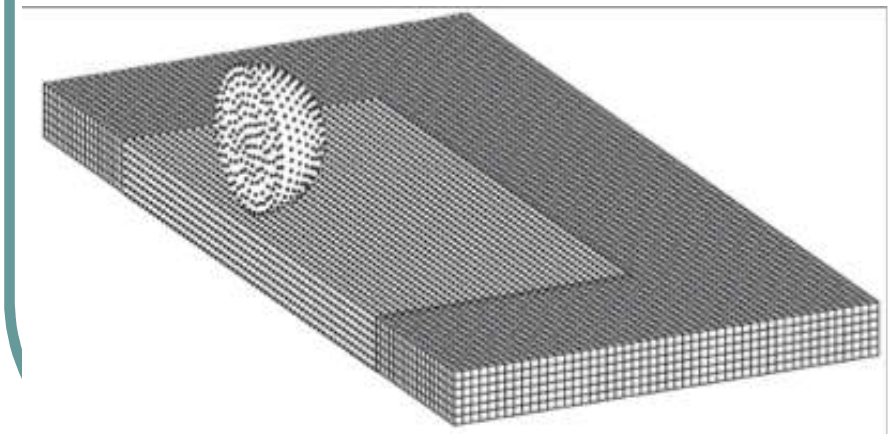
- YP Lian, X Zhang, et al. Coupling of finite element method with material point method by local multi-mesh contact method. ***CMAME*** 200: 3482-3494, 2011
- ZP Chen, XM Qiu, X Zhang, et al. Improved coupling of finite element method with material point method based on a particle-to-surface contact algorithm. ***CMAME*** 293(15): 1-19, 2015

Finite Element Material Point Methods

- Material domain is discretized by a mesh of finite elements
- A predefined grid is placed in the potential large deformation zone
- Momentum equations are solved on
  - Background grid — large deformation zone
  - FE mesh — elsewhere





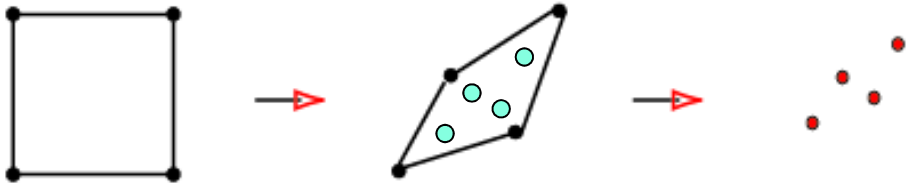


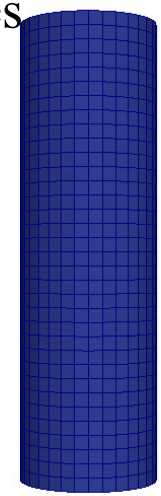
X Zhang， KY Sze, et al. An explicit material point finite element method for hyper velocity impact. ***International Journal for Numerical Methods in Engineering*** 66: 689 ~706, 2006

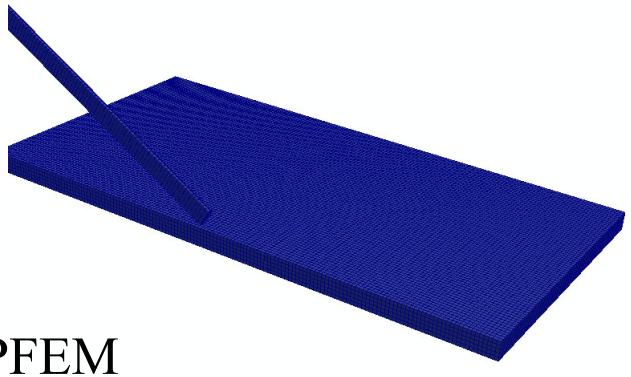
Finite Element Material Point Methods

Adaptive FE - MP Method

- Distorted elements are adaptively converted into MPM particles
  - When to convert – avoid element distortion
    - Effective plastic strain
    - Critical time step
  - How to convert
    - Conservation of mass/momentum/ energy
    - New particles are placed at (± 0.5, ± 0.5, ± 0.5)







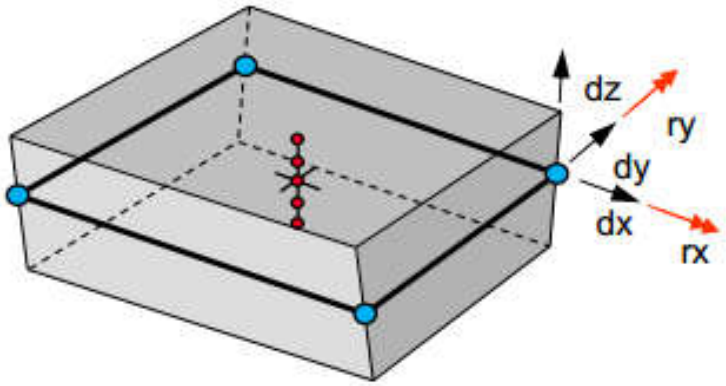
  - After conversion
    - Particles and remaining elements are coupled in a similar way to that used in MPFEM

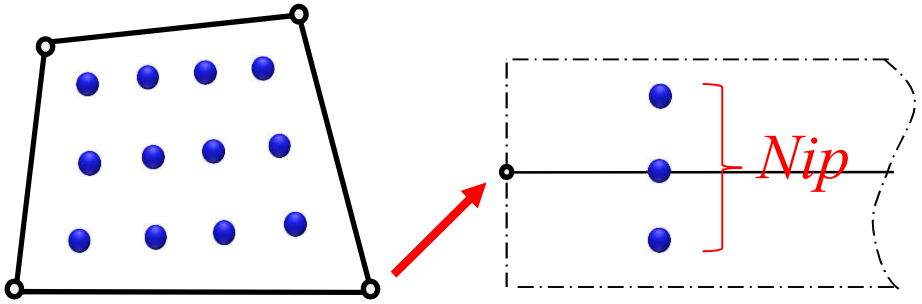
YP Lian, X Zhang, et al. An adaptive finite element material point method and its application in extreme deformation problems. ***CMAME*** 241-244 (1): 275~285, 2012
ZP Chen, XM Qiu, X Zhang, et al. Improved coupling of finite element method with material point method based on a particle-to-surface contact algorithm. ***CMAME*** 293(15): 1-19, 2015

Finite Element Material Point Methods

Coupled shell-particle

- **Coupled shell-particle method**
  - Belytschko and Tsay 1981
  - Particle-surface contact
- Adaptive shell-particle method
  - Conversion criteria
    - Element aspect ratio
    - Plastic strain
  - Conversion method
    - *Nip* layers in the thickness direction
    - *Nx* ×*Ny* particles in each layer

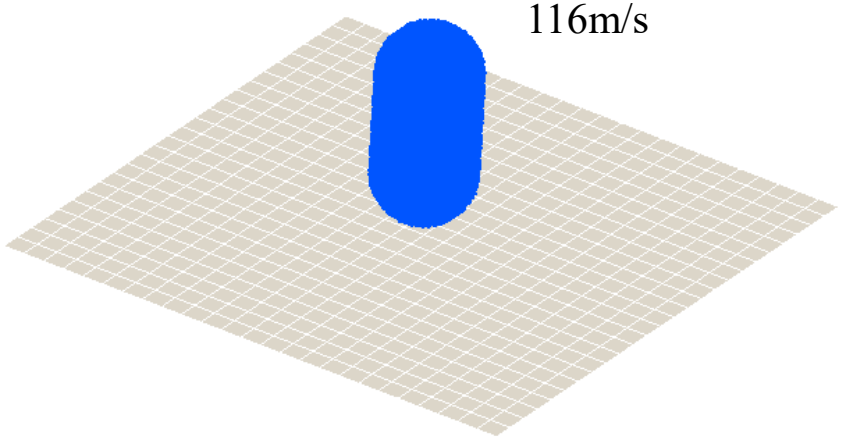




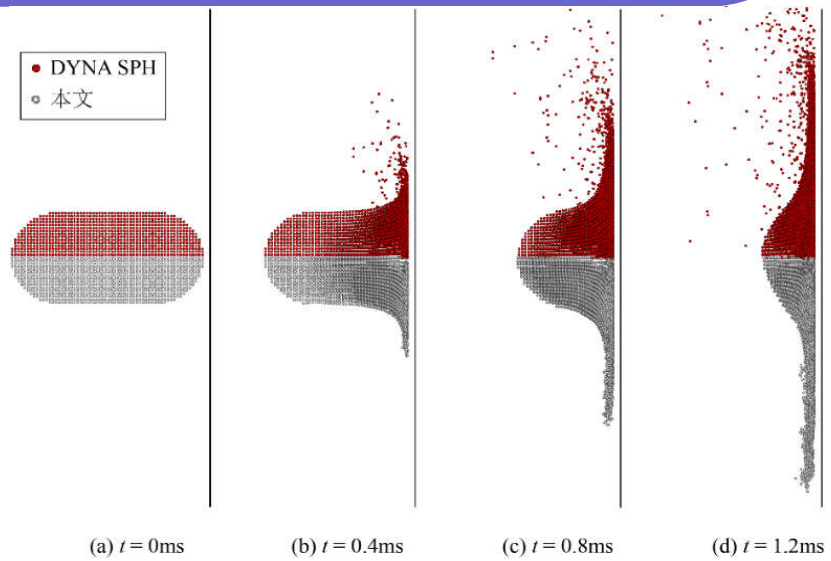
Finite Element Material Point Methods

Coupled shell-particle

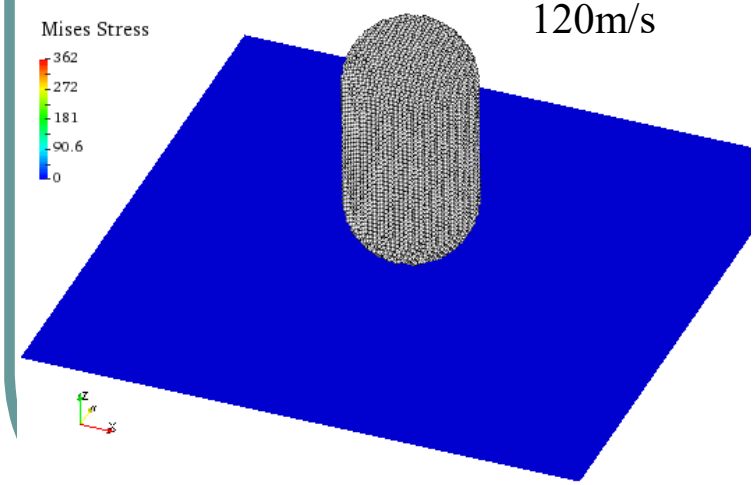
116m/s



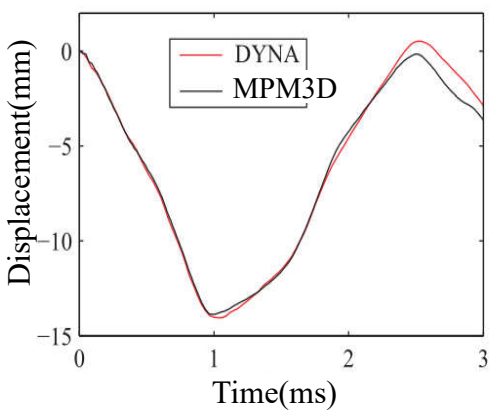
Bird strike on a rigid plate

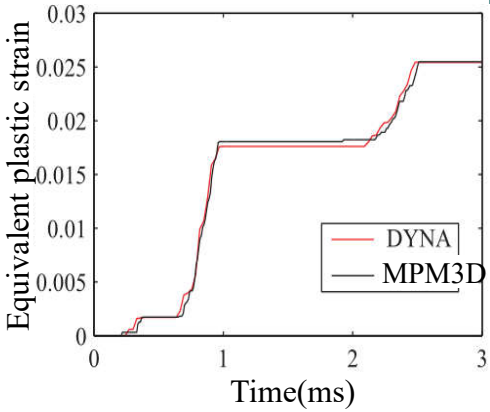


120m/s



Bird strike on an aluminum plate

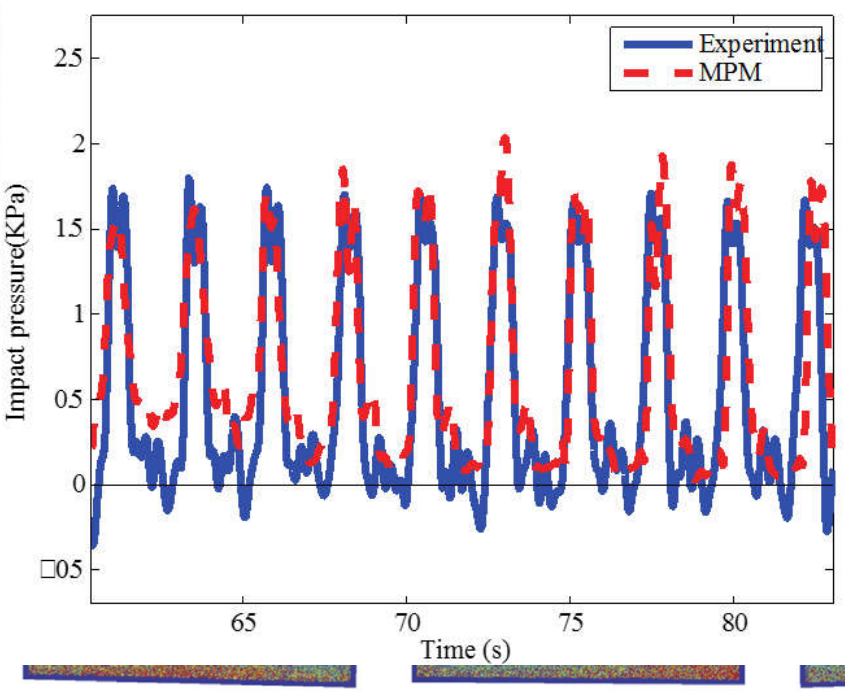


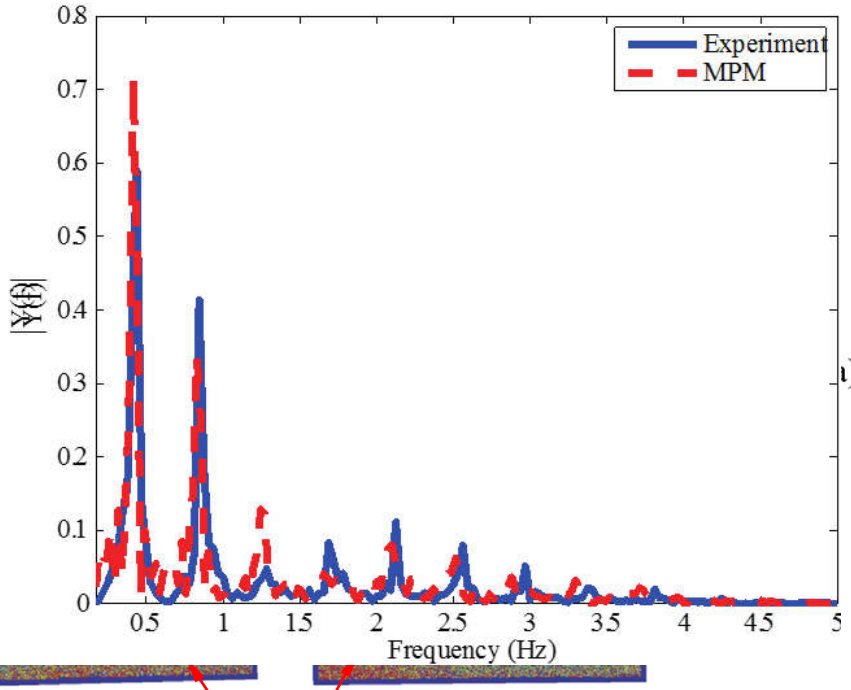


Displacement and equivalent plastic strain at center

Weakly compressible EOS $p = c^2 \rho$

Density fluctuation: $\delta = \Delta\rho / \rho_0 = v_f^2 / c^2$ $\quad \delta \le 1\% \Rightarrow c \ge 10 v_f$





$t = 63.69$s $\quad t = 64.28$s $\quad t = 64.87$s $\quad t = 65.46$s

$\Delta t = 5.5 \times 10^{-5}$ s

Pressure is not smooth

JG Li, Y Hamamoto, Y Liu, X Zhang. Sloshing impact simulation with material point method and its experimental validations. ***Computers & Fluids***, 103(1): 86 ~ 99, 2014

Finite Element Material Point Methods

Incompressible fluid

$$\frac{\mathrm{d}\boldsymbol{v}}{\mathrm{d}t} = -\frac{1}{\rho}\nabla p + \frac{1}{\rho}\nabla\cdot\boldsymbol{\tau} + \boldsymbol{b}$$

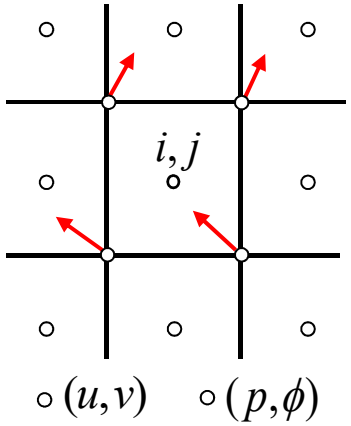
Operator split:

$$\frac{\mathrm{d}\boldsymbol{v}}{\mathrm{d}t} = \frac{1}{\rho}\nabla\cdot\boldsymbol{\tau} + \boldsymbol{b} \longrightarrow \boldsymbol{v}^{*} = \boldsymbol{v}^{n} + \Delta t\left(\frac{1}{\rho}\nabla\cdot\boldsymbol{\tau} + \boldsymbol{b}\right) \text{(explicit MPM)}$$

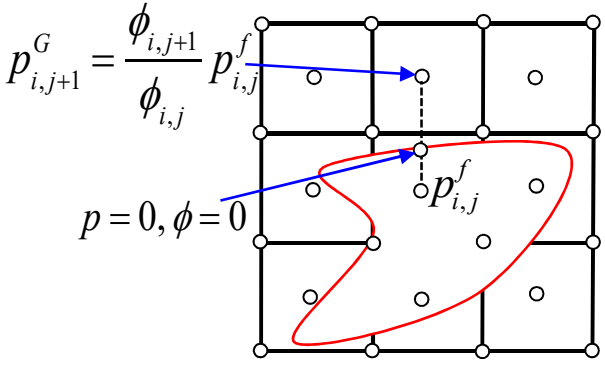
$$\frac{\mathrm{d}\boldsymbol{v}}{\mathrm{d}t} = -\frac{1}{\rho}\nabla p \longrightarrow \boldsymbol{v}^{n+1} = \boldsymbol{v}^{*} - \Delta t\frac{1}{\rho}\nabla p^{n+1} \xrightarrow{\nabla\cdot\boldsymbol{v}^{n+1}=0} \nabla^{2}p^{n+1} = \frac{\rho}{\Delta t}\nabla\cdot\boldsymbol{v}^{*}$$

(pressure Poisson equation)

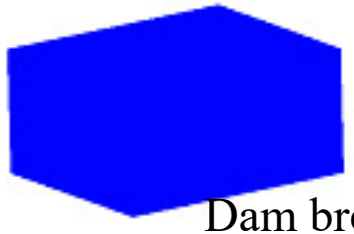
- PPE is solved by collocating at cell centers
- Level set is used to construct the free surface



Semi-Staggered grid



Pressure boundary condition



Dam break simulation

F Zhang, X Zhang, et al. Incompressible material point method for free surface flow. ***Journal of Computational Physics***. Minor revision.

- Fluid domain (iMPM)

$$\boldsymbol{v}^{*} = \boldsymbol{v}^{n} + \Delta t(\frac{1}{\rho}\nabla\cdot\boldsymbol{\tau} + \boldsymbol{b})$$

$$\nabla^2 p^{n+1} = \frac{\rho}{\Delta t}\nabla\cdot\boldsymbol{v}^{*} \Longleftrightarrow \min_{p} W[p] \quad \text{(C. Batty et al. 2007)}$$

$$\Downarrow \text{Collocated at cell centers}$$

$$\boldsymbol{A}\boldsymbol{p}^{n+1} = \boldsymbol{b}$$

$$\frac{\partial W[p]}{\partial p} = \frac{\partial W_{\text{fluid}}[p]}{\partial p} + \frac{\partial W_{\text{solid}}[p]}{\partial p} = 0$$

$$\Downarrow \qquad \Downarrow$$

$$\boldsymbol{A}\boldsymbol{p}^{n+1} - \boldsymbol{b} - \boldsymbol{b}^{*} = 0 \xrightarrow{\text{PCG}} \boldsymbol{p}^{n+1}$$

- Solid domain (Explicit FEM)

$$\boldsymbol{M}\dot{\boldsymbol{v}} = \boldsymbol{f}^{\text{int}} + \boldsymbol{f}^{\text{ext}}$$

- Fluid-Solid interface

$$W_{\text{solid}}[p] = \int_{\Gamma_C} p\hat{\boldsymbol{n}}\cdot\boldsymbol{v}_{\text{solid}}\Delta t\,\mathrm{d}\Gamma = \Delta t\int_{\Omega}\nabla\cdot(p\boldsymbol{v}_{\text{solid}})\mathrm{d}\Omega$$

$$\boldsymbol{v}^{\text{f}}\cdot\boldsymbol{n} = \boldsymbol{v}^{\text{s}}\cdot\boldsymbol{n}$$

- Coupling Fluids and Solids: Weak Coupling
  - Solid provides *velocity boundary condition* to update the fluid pressure
  - Fluid provides *boundary forces* to update the solid velocities

$$\boldsymbol{M}\dot{\boldsymbol{v}}^{\text{s}} = \boldsymbol{f}^{\text{int}} + \boldsymbol{f}^{\text{ext}} + \boldsymbol{f}^{\text{c}} \qquad \boldsymbol{f}^{\text{c}} = \int_{\Gamma_c} -\boldsymbol{N}^{\text{T}} p^{n+1}\hat{\boldsymbol{n}}\,\mathrm{d}\Gamma$$

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  - Impact/Penetration
  - Hypervelocity impact
  - Blast loading
  - Free surface flow
  - Fluid-structure interaction
  - Slope failure
  - Metal cutting
  - Fracture silumation
  - Bio-mechanics
- Concluding remarks

Applications

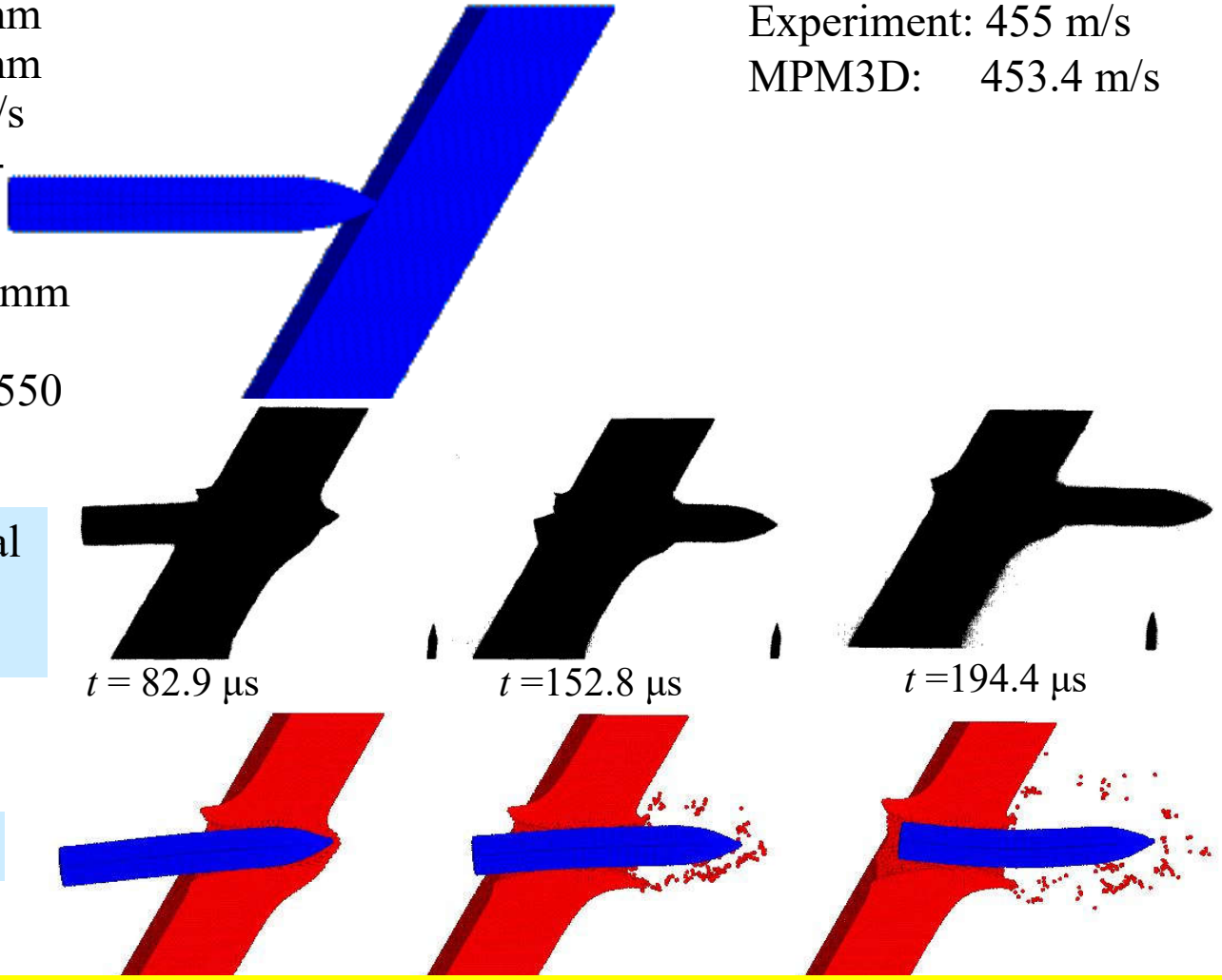
Penetration

Projectile: Steel
- Length: 88.9 mm
- Diamete: 12.9 mm
- Velocity: 575 m/s
- Particles: 13,314

Target: Aluminium
- Thickness: 26.3mm
- Inclination: 30°
- Particles: 187,550

Piekutowski, Forrestal et al. ***IJIE*** 1996; 18: 877-887

Projectile's residual velocity
- Experiment: 455 m/s
- MPM3D: 453.4 m/s

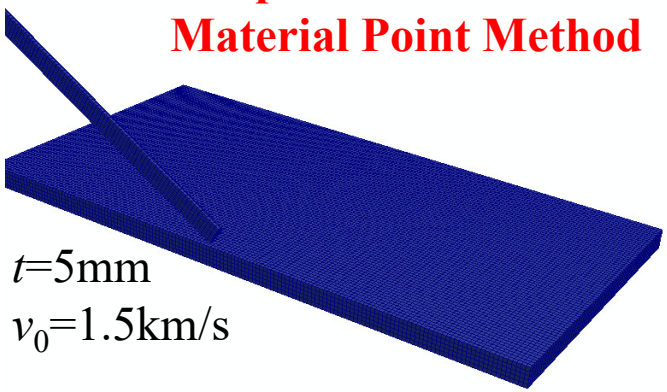


P Huang, X Zhang et al. Contact Algorithms for the Material Point Method in Impact and Penetration Simulation. ***International Journal for Numerical Method in Engineering*** 85(4): 498-517, 2011

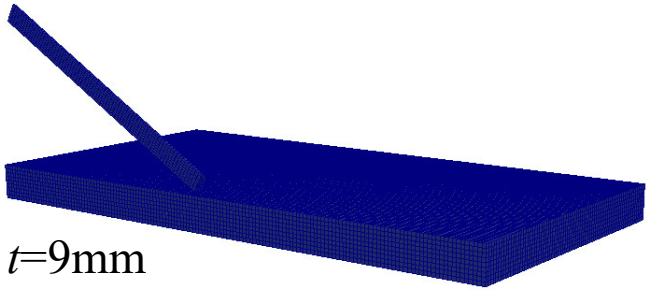
Applications

Penetration

Adaptive Finite Element Material Point Method



t=5mm
v_0=1.5km/s



t=9mm
v_0=2.5km/s

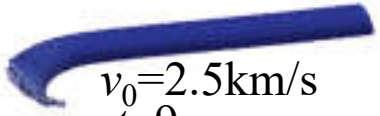
Projectile: Tungsten alloy
L_0 = 75, D_0 = 5mm
v_0 = 1500 m/s
Incidence angle = 60°

Target: Armor steel
t = 5/9 mm
L_0=150 mm
W_0 = 150 mm

Cases		Residual length L/L_0	Residual velocity v/v_0
t=5 v_0=1.5	Experiment	0.85	0.97
	MPM3D	0.82	0.96
t=9 v_0=2.5	Experiment	0.76	0.99
	MPM3D	0.72	0.97

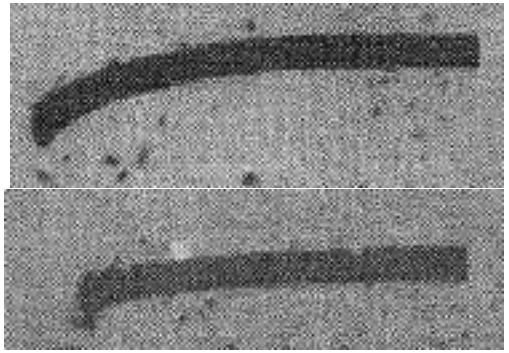


v_0=1.5km/s
t=5mm



v_0=2.5km/s
t=9mm

MPM3D



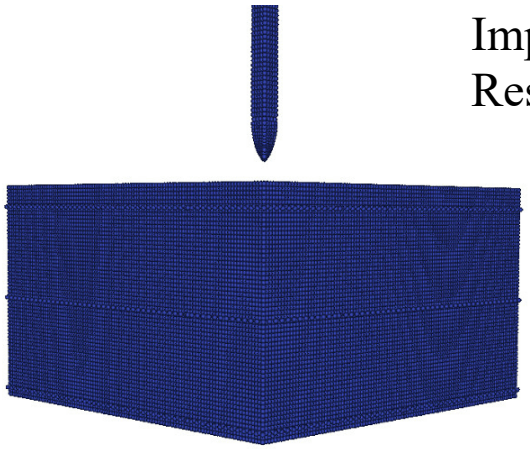
Experiment (Holmberg, Lundberg et al. 1993)

YP Lian, X Zhang, et al. An adaptive finite element material point method and its application in extreme deformation problems. ***CMAME*** 241–244 (1): 275–285, 2012

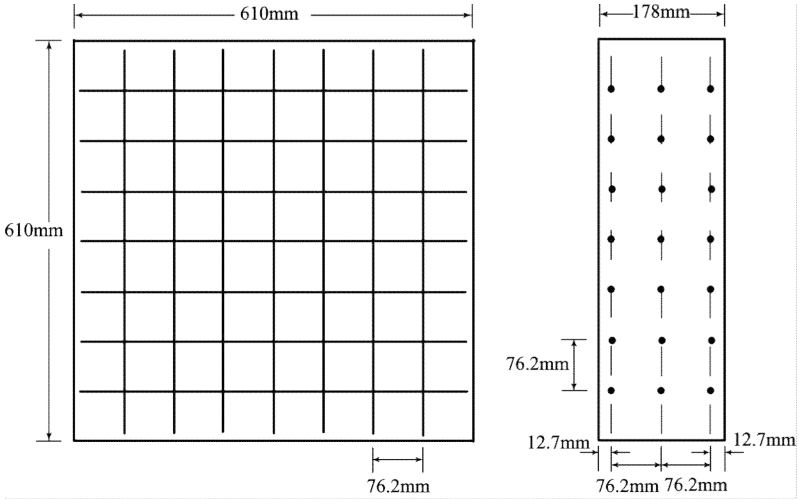
Applications

Penetration: C48 RC

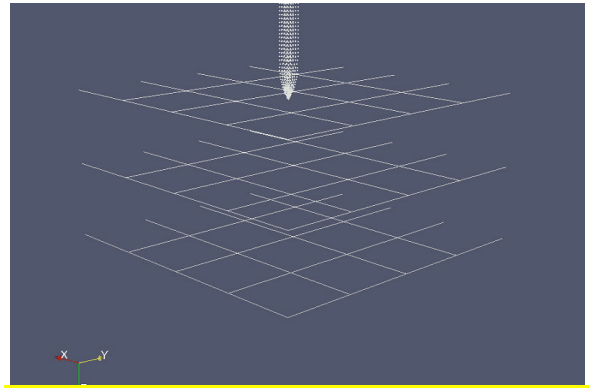
Hybrid Finite Element Material Point Method

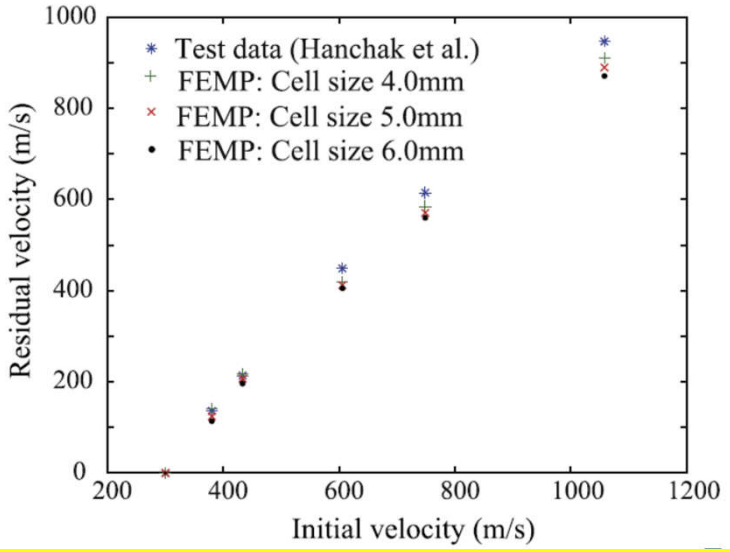


Impact velocity: 746 m/s
Residual velocity
Experiment: 615m/s
MPM3D: 585m/s



Hanchak et al. ***IJIE*** 1992; 12(1): 1-7





YP Lian, X Zhang, et al. A FEMP method and its application in modeling dynamic response of reinforced concrete subjected to impact loading. ***CMAME*** 200(17-20), 1659-1670, 2011

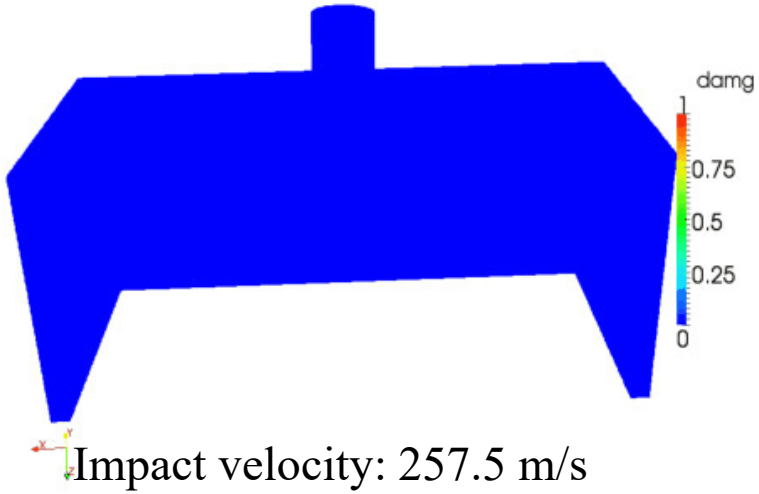
Applications

Reinforced Concrete

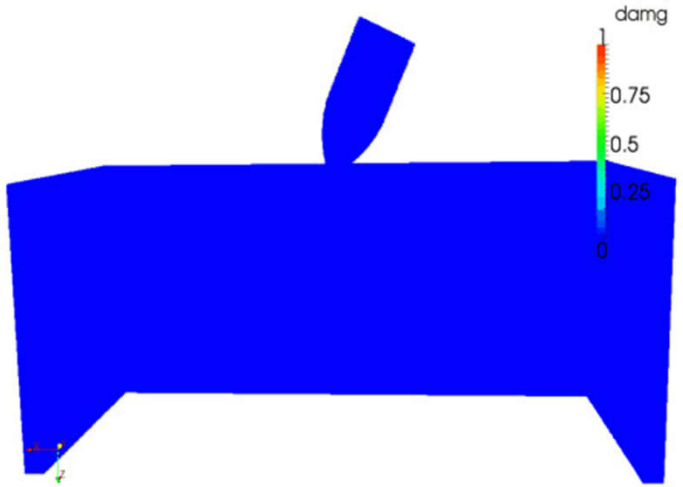
Impact Velocity (m/s)	Residual Velocity (m/s)		Perforation Pore Diameter (mm)	
	Experiment	MPM3D	Experiment	MPM3D
257.5	100.7	100	780×710	900×1000
248.3	83.7	83	930×730	1000×1000



Hybrid Finite Element Material Point Method



Impact velocity: 257.5 m/s
Incident angle: 1°



Impact velocity: 248.3 m/s
Incident angle: 24.5°

Applications

Cohesive soil impact

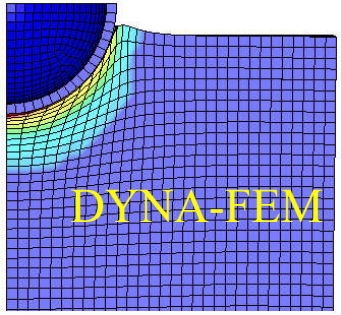


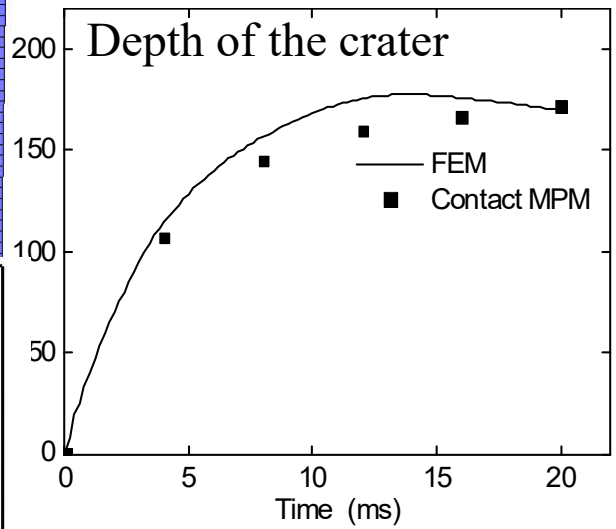
Half spherical shell:
Diameter: 0.408m
Mass: 12kg
Al alloy

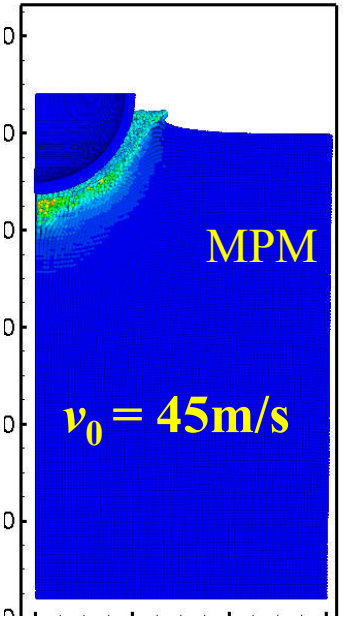
Fasanella E L, et al. AIAA, 2001

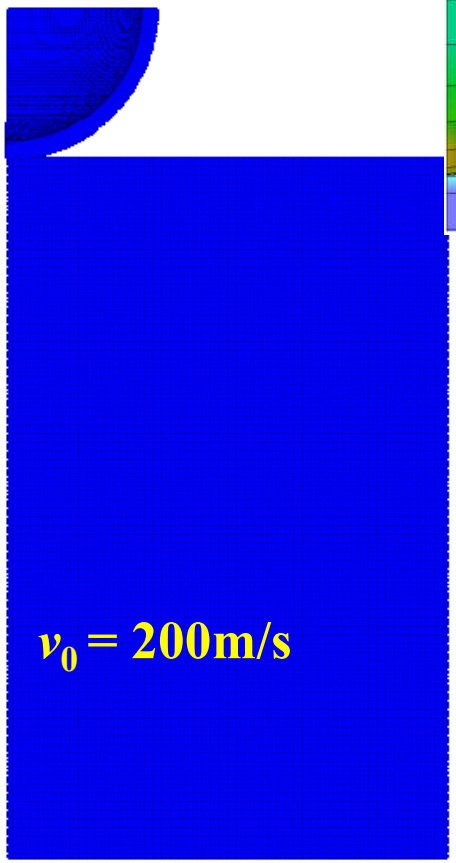
Particles for spherical shell: 26385
Particles for target: 1600000

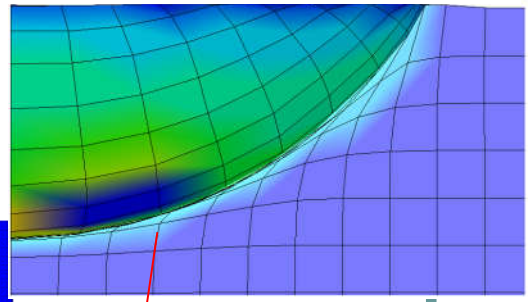
LS-DYNA FEM calculation terminated abnormally due to element distortion

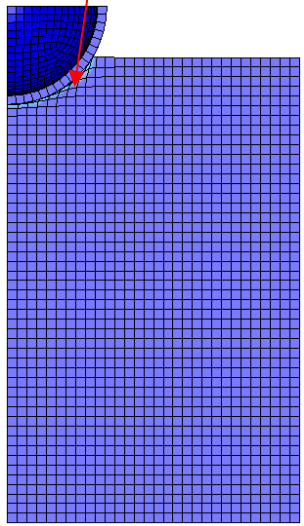






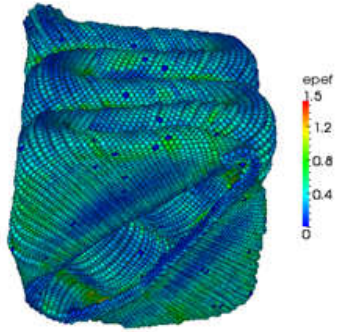






Applications

Crush of Thin Tubular Columns

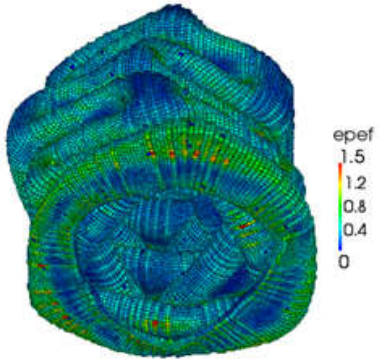


(a) simulation



(b) experiment [7]

t/d=0.063 $\bar{P}$ = 2.7kN

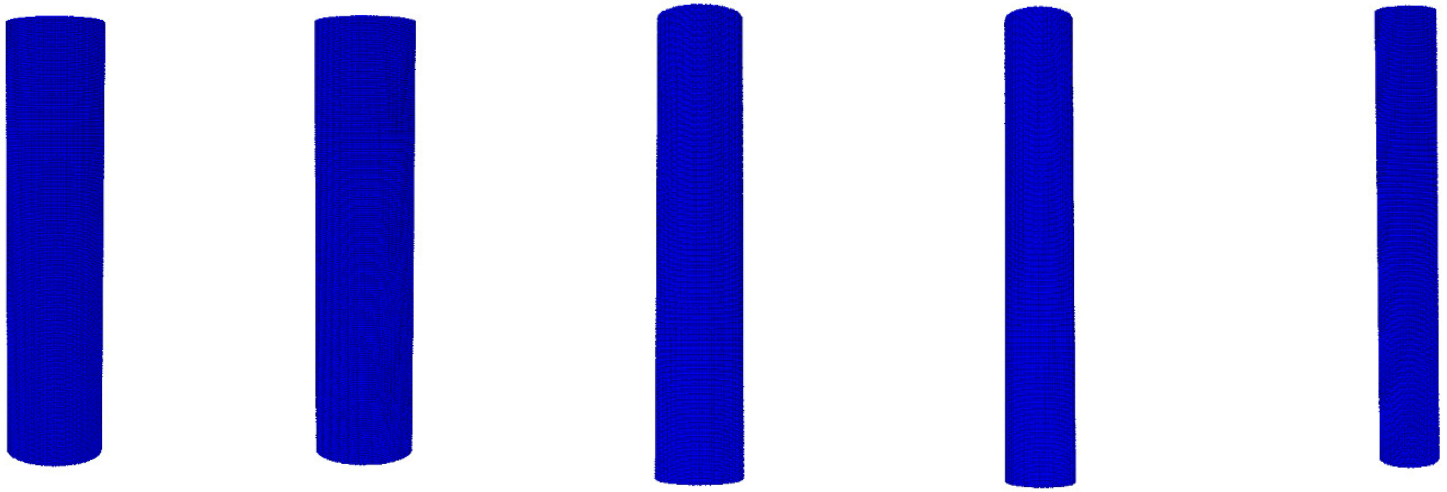


(a) simulation



(b) experiment [7]

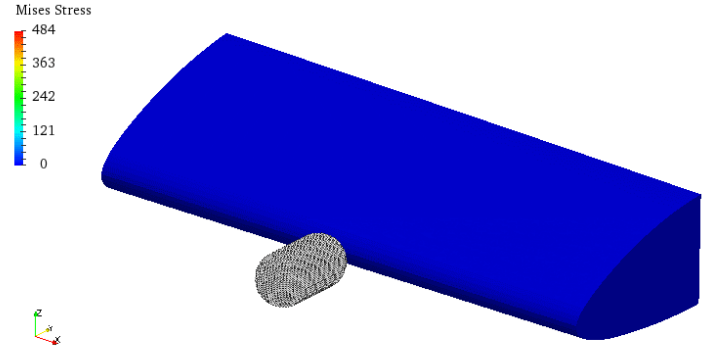
t/d=0.038 $\bar{P}$ = 1.0kN

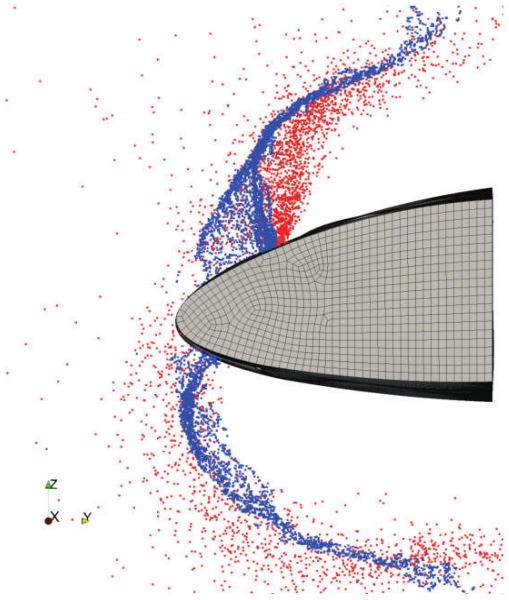


PF Yang, S A Meguid, X Zhang. Accurate modeling of the crush behaviour of thin tubular columns using material point method. ***SCIENCE CHINA Physics, Mechanics & Astronomy***. 56(2): 1~11, 2013

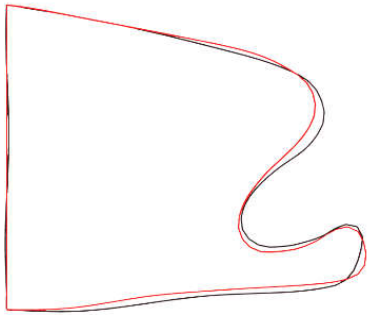
Applications

Bird Strike Leading Edge

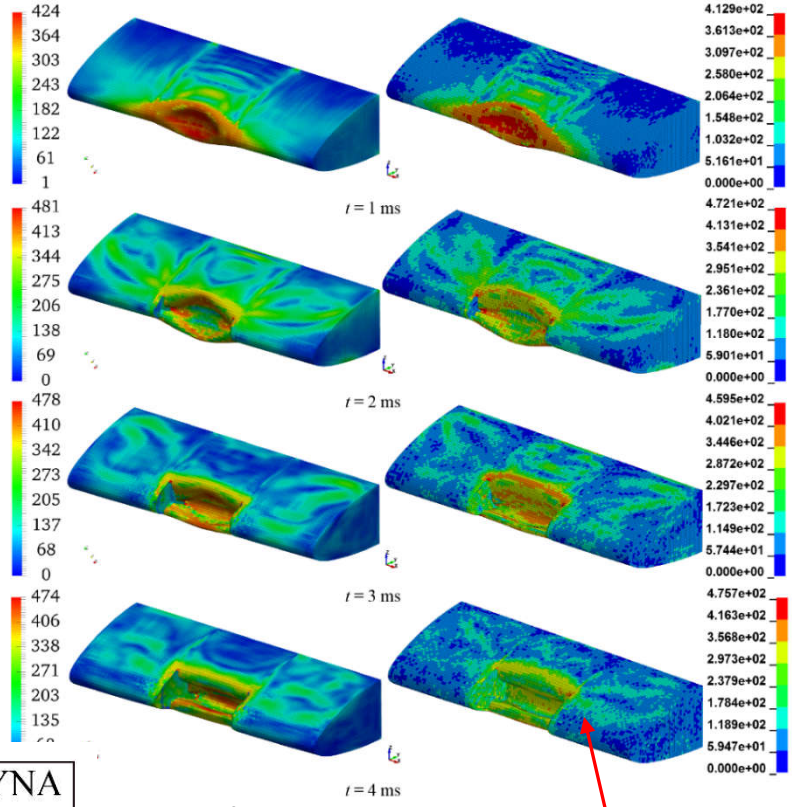




Bird deformations at 4 ms
- Red: DYNA-SPH bird
- Blue: MPM bird



Cut shapes at 4 ms





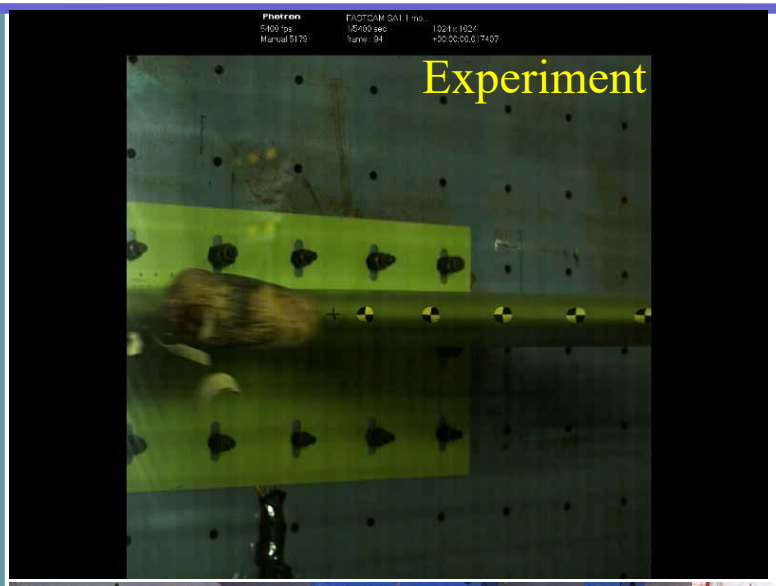
MPM3D LS-DYNA

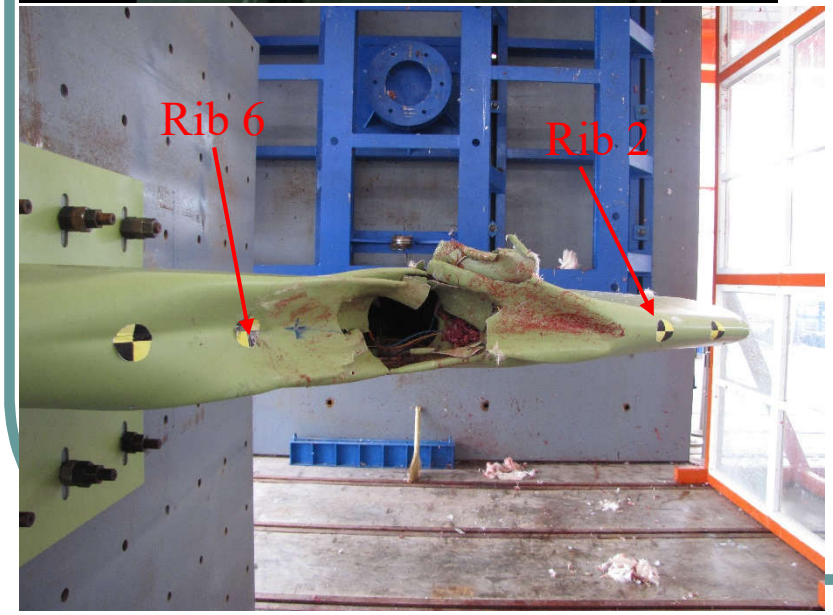
von Mises stress

noisy

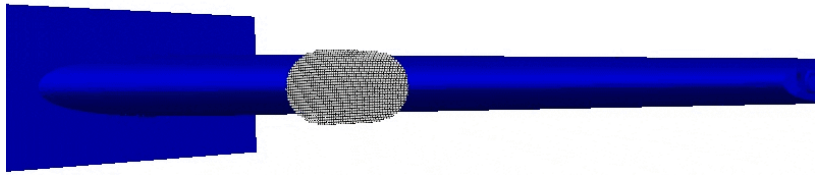
Applications

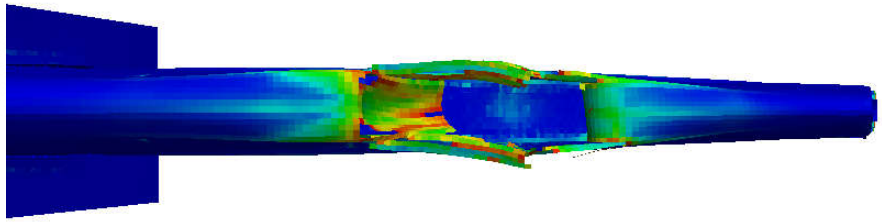
Bird Strike Empennage

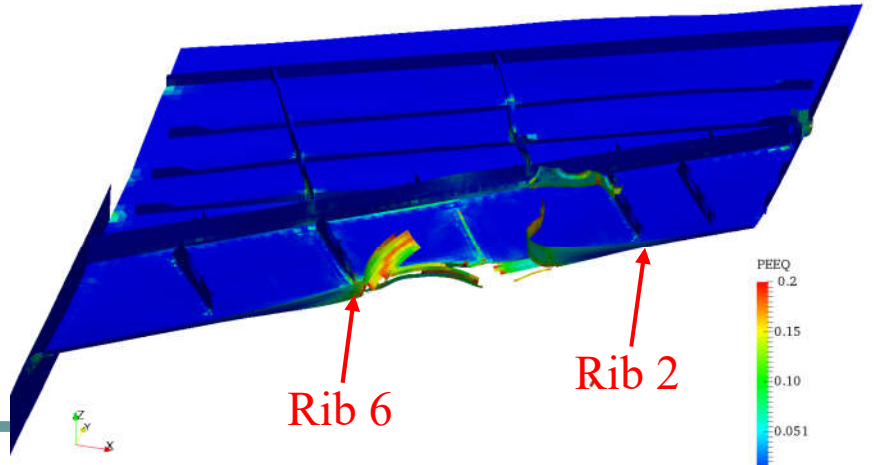




MPM3D



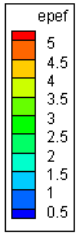


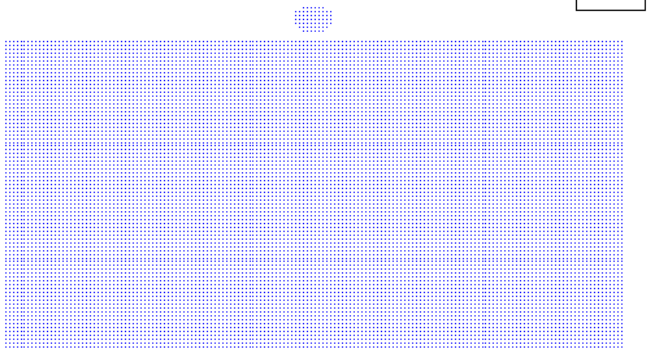


Applications

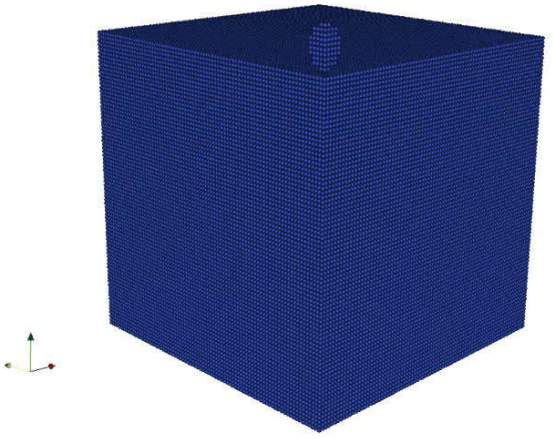
Crater forming

- Impact velocity： 6.0 km/s
- Projectile mass： 0.5 g
- L = 80mm, H = 40mm
- **1,024,224** particles
- Run 1h 55m in P4 2.8G PC for simulation time of 32ms
- Time step size = 46.2 μs
- Steps: 692 steps





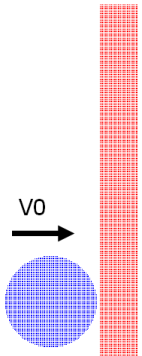
	Deepness (mm)	Diameter (mm)	Deepness / Diameter
Experiment*	14	25.4	0.55
EPIC	18	24	0.75
MESA	15.9	28	0.57
SPH	17.3	26	0.67
CALE	15.1	24.4	0.62
MPM3D	14	25	0.56



Applications

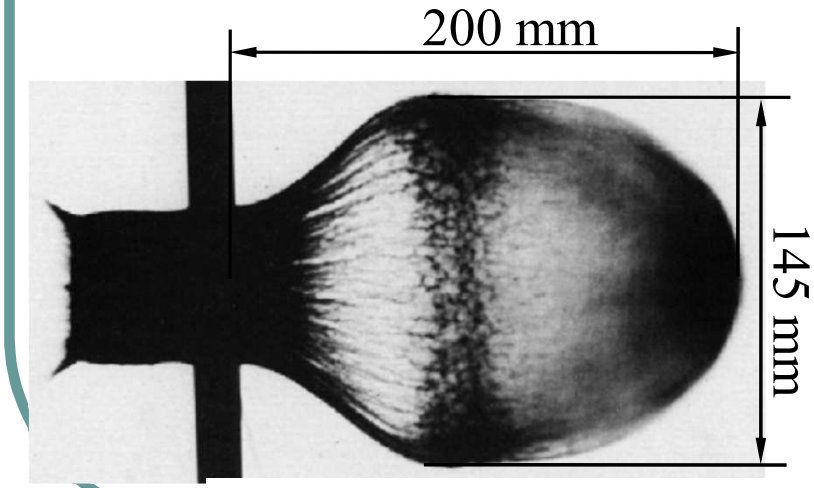
Debris cloud

- Projectile: Lead sphere, r =7.5mm, m = 20g
- Target: Lead plate, t = 6.35 mm
- Impact velocity: v_0 = 6.58 km/s
- Material model
  - Elastic-plastic constitutive model
  - Mie-Grüneisen EOS
- Material failure model
  - Tensile Failure ($P_{\min}$ = −1500 MPa)
  - Plastic Strain Failure ($\varepsilon_{p\max}$= 3.0)

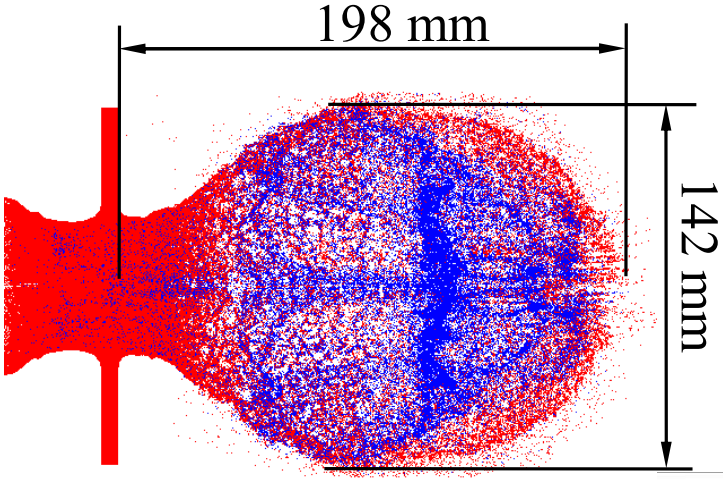


2 Quad-Core Xeon
2.66 GHz processors
(OpenMP): 1.93h

The debris cloud at 30.6 μs



Experimental radiograph (Anderson, 1990)

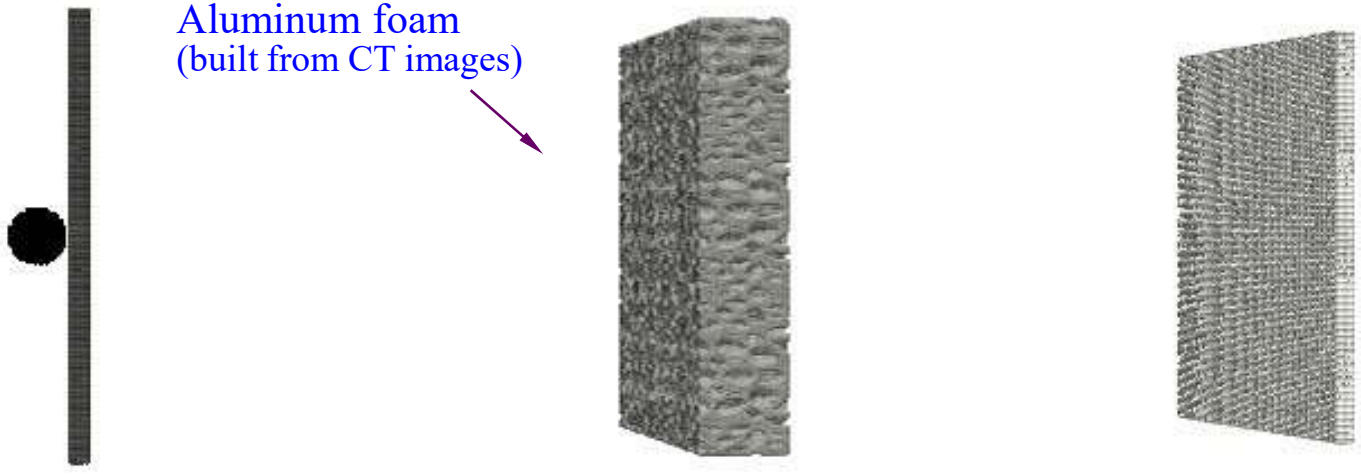


13,542,030 particles

omputational Dynamics
计算动力学实验室

Applications

Space debris shielding



The first bumper after impact



2190m/s 3410m/s 4060m/s

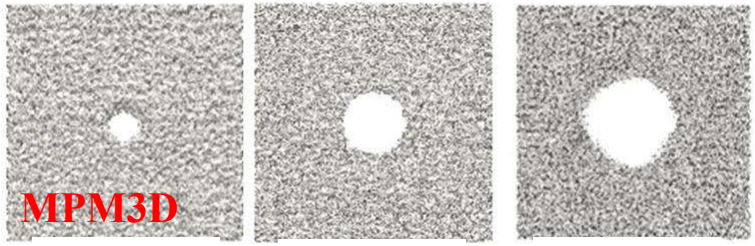


2190m/s 3410m/s 4060m/s

The second bumper after impact



2190m/s 3410m/s 4060m/s

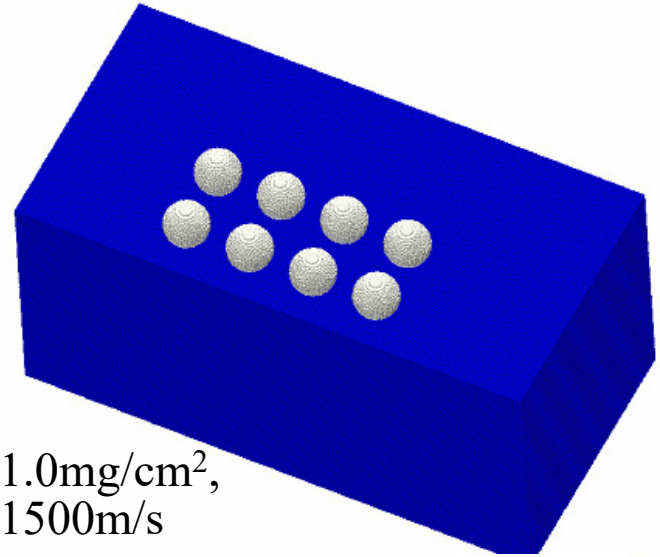


2190m/s 3410m/s 4060m/s

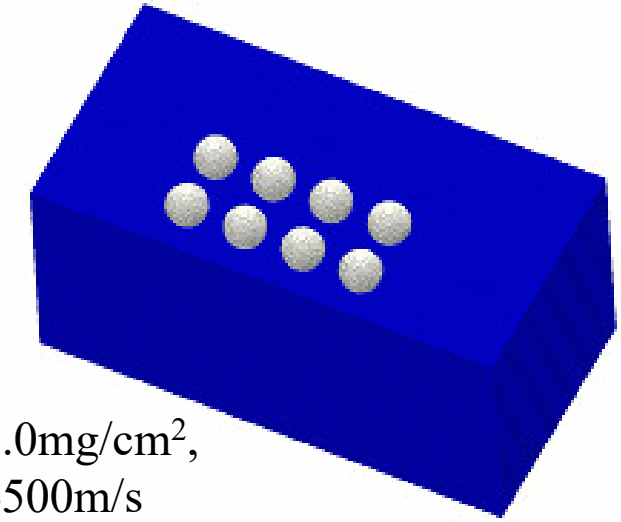
WW Gong, Y Liu, X Zhang, et al. Numerical Investigation on Dynamical Response of Aluminum Foam Subject to Hypervelocity Impact With Material Point Method. ***CMES*** 83(5): 527-545, 2012

Applications

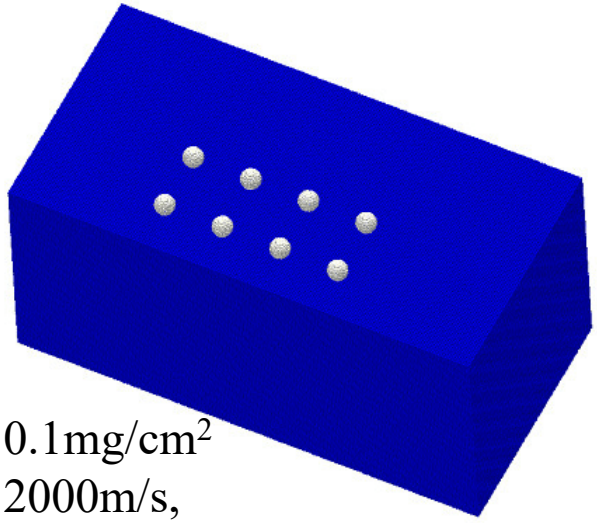
High-Velocity Impact of Micron Particles



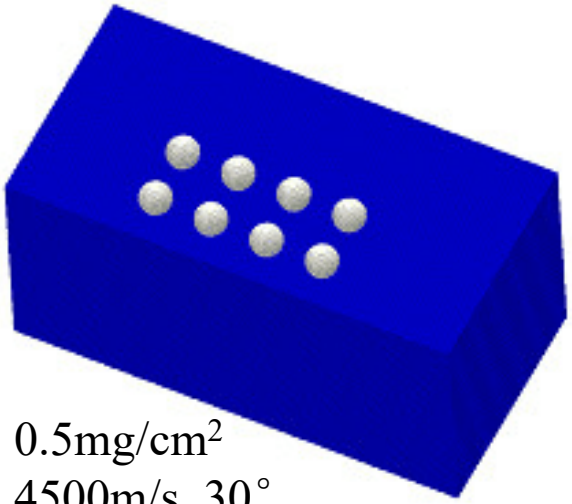
1.0mg/cm^2,
1500m/s



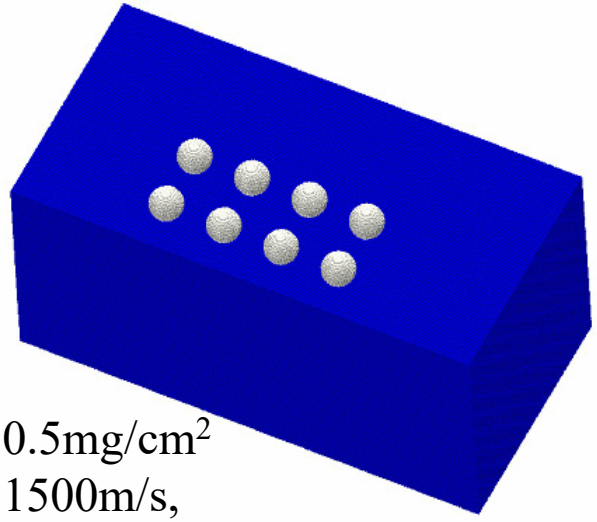
1.0mg/cm^2,
4500m/s



0.1mg/cm^2
2000m/s,



0.5mg/cm^2
4500m/s, 30°



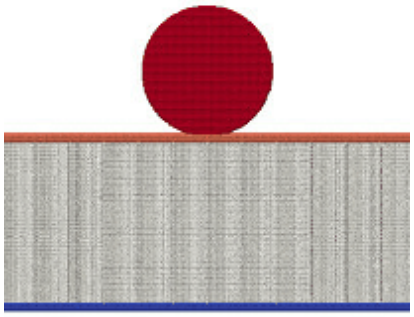
0.5mg/cm^2
1500m/s,

P Liu, Y Liu, X Zhang. Investigation on High-Velocity Impact of Micron Particles using Material Point Method. ***International Journal of Impact Engineering***. 75: 241–254, 2015

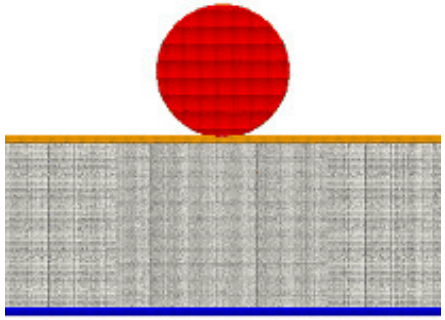
Applications

Honeycomb Sandwich Panel

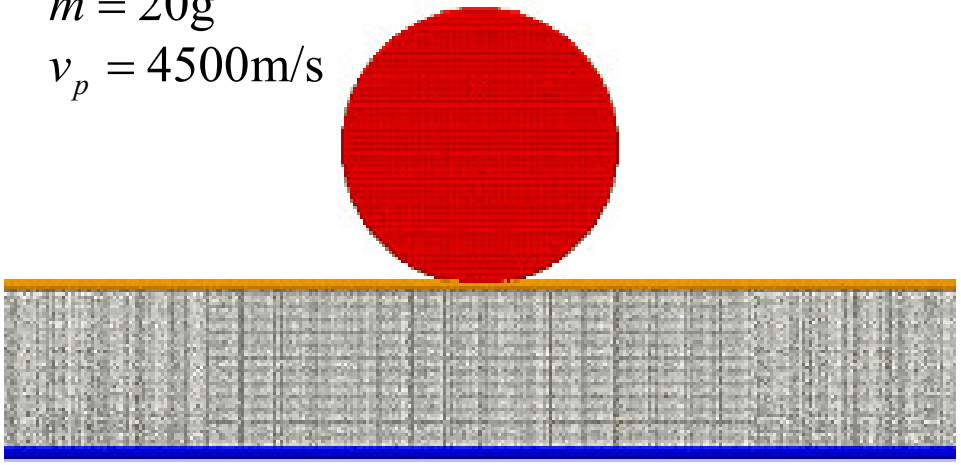
$m = 2\text{g}$
$v_p = 1300\text{m/s}$

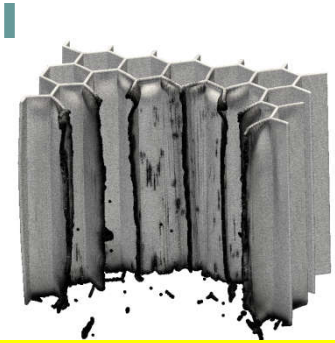


$m = 2\text{g}$
$v_p = 4500\text{m/s}$

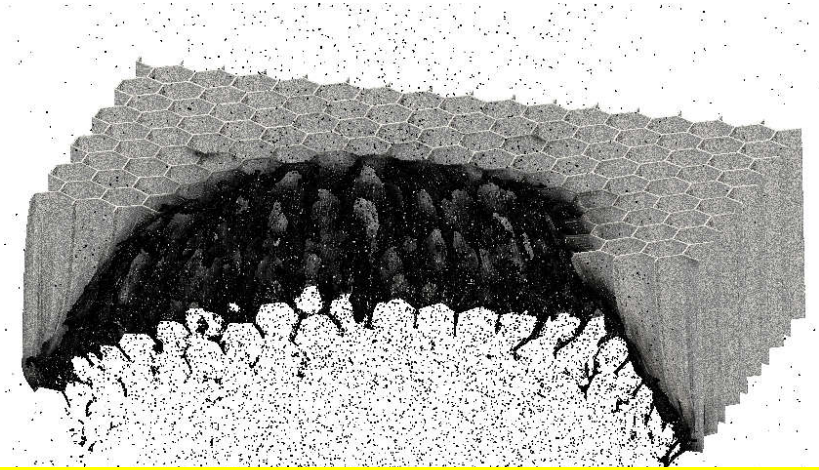


$m = 20\text{g}$
$v_p = 4500\text{m/s}$





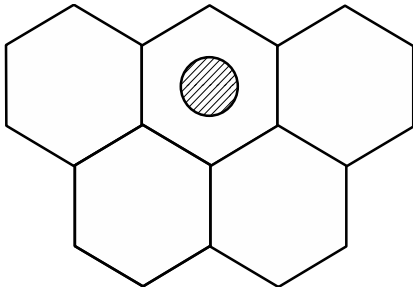


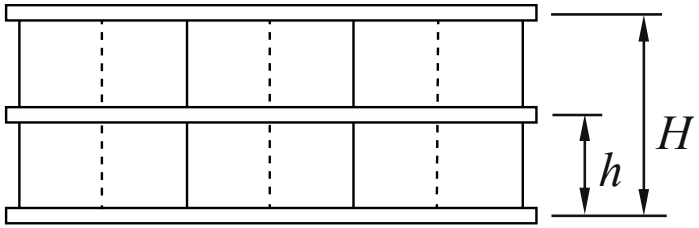


P Liu, Y Liu, X Zhang. Internal-structure-model Based Simulation Research of Shielding Properties of Honeycomb Sandwich Panel Subjected to High-Velocity Impact. ***IJIE***. 77:120 - 133, 2015.

Applications

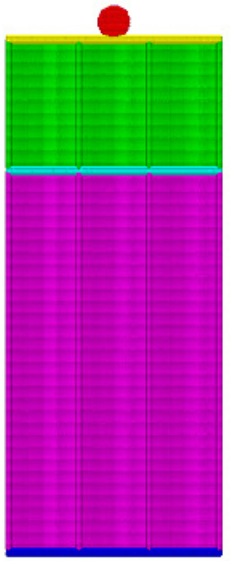
Double honeycomb structure

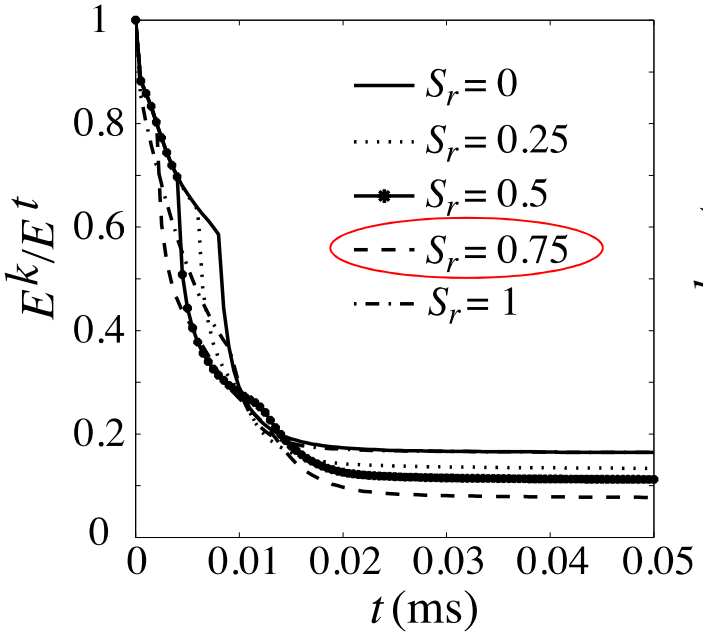




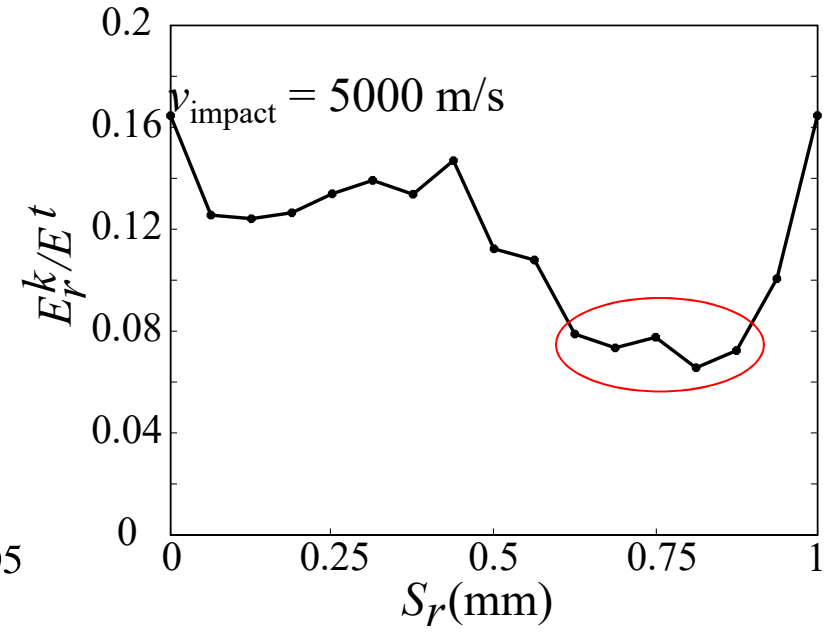
$S_r = h/H$

$S_r = 0.75$





Dimensionless kinetic energy

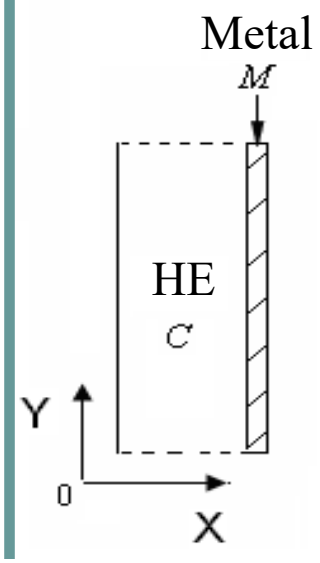


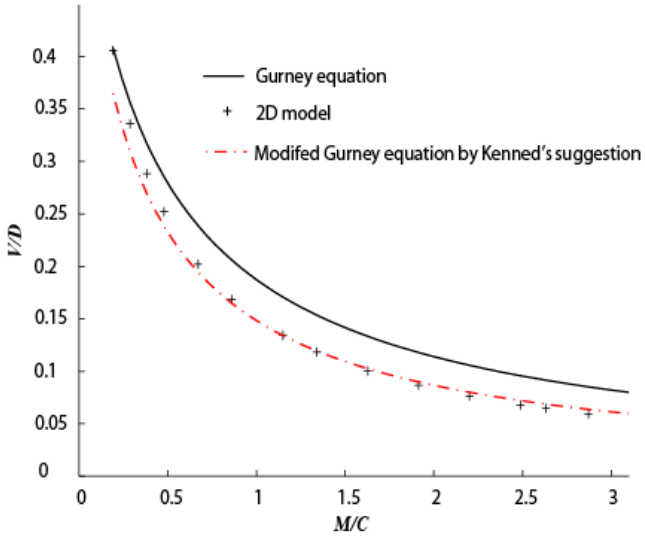
Residual kinetic energy

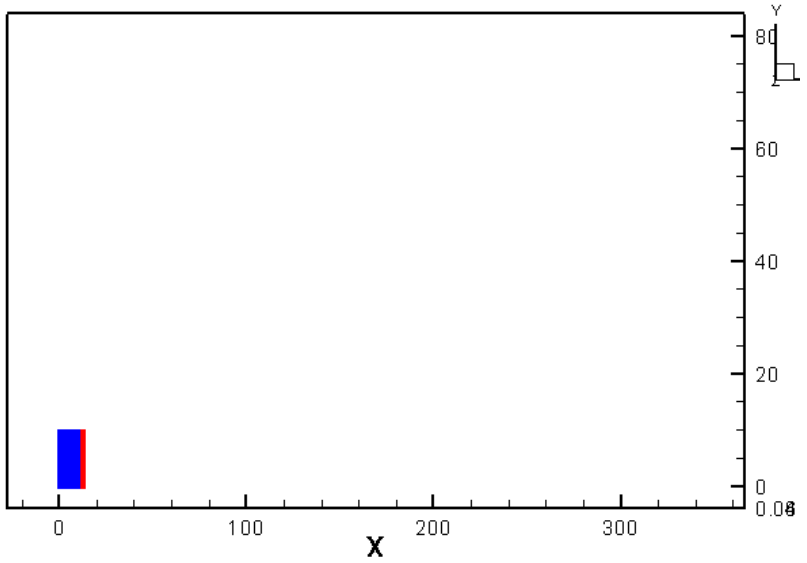
P Liu, Y Liu, X Zhang. Simulation of Hyper-velocity Impact on Double Honeycomb Sandwich Panel and Its Staggered Improvement with Internal-structure Model. ***International Journal of Mechanics and Materials in Design***. 12(2): 241-254, 2016

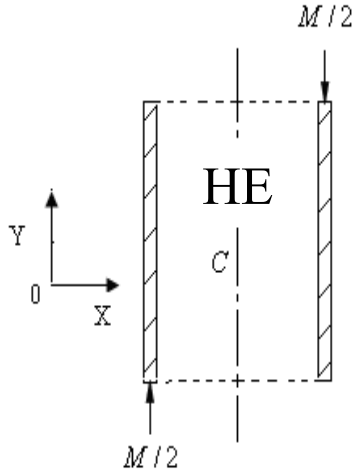
Applications

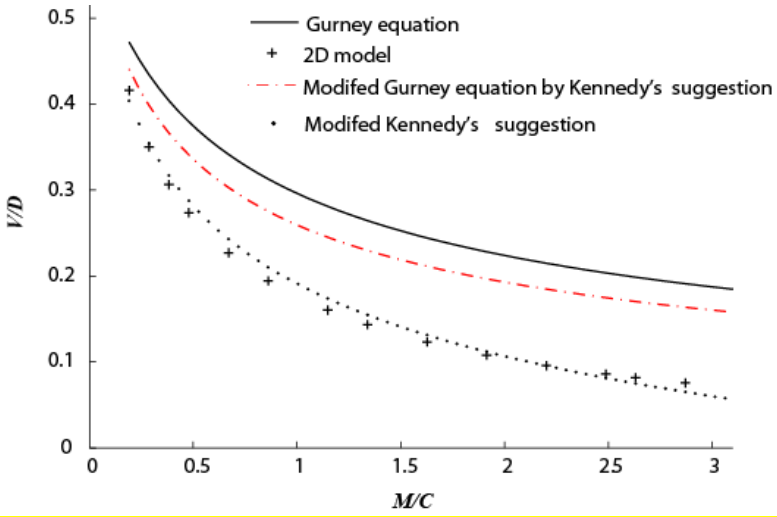
Explosive driven Metal









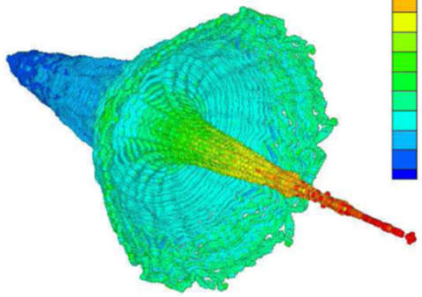


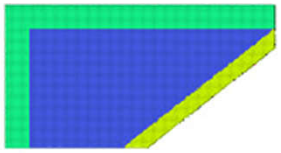
YP Lian, X Zhang, et al. Numerical Simulation of Explosively Driven Metal by Material Point Method. ***International Journal of Impact Engineering*** 38(4): 237-245, 2011

Applications

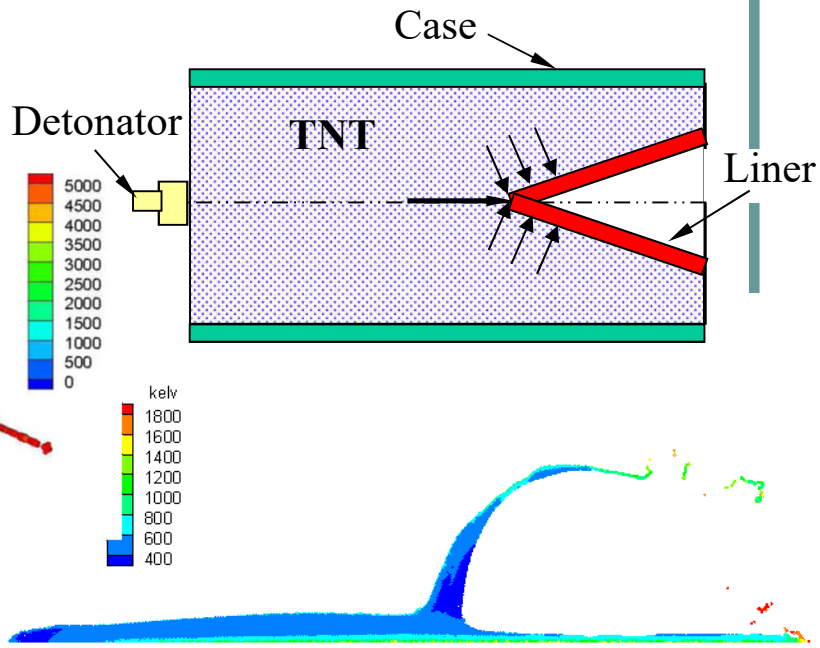
Shaped charge

- Shaped charge
  - A cylinder of high explosive with a cone-shape thin metal liner in one end
  - Intense pressure ➔ Collapse of the liner ➔ A jet with extreme high velocity (> 10 km/s)
- Application
  - Armor penetration
  - Metal cutting
  - Oil well perforation

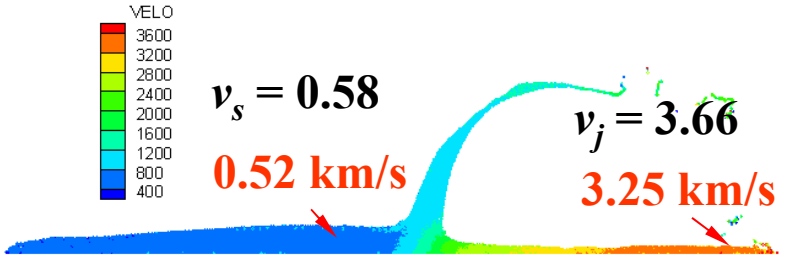








Temperature distribution



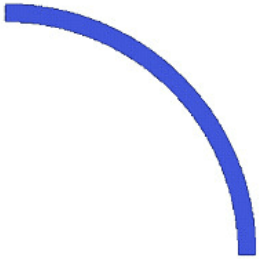
Velocity distribution

S Ma, X Zhang, et al. Simulation of high explosive explosion using adaptive material point method. ***CMES*** 39(2):101-123, 2009

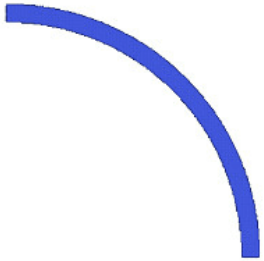
Applications

Fragmentation driven by explosion

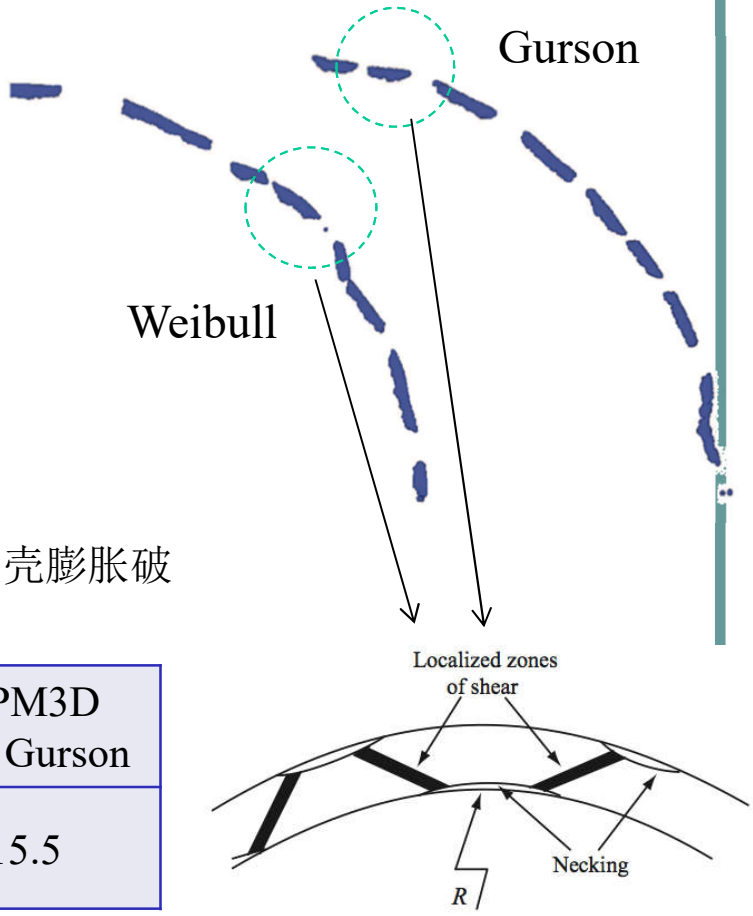
Metal shell driven by High explosive



Weibull random failure



Gurson model



Experiment: 汤铁钢, 谷岩, 李庆忠. 爆轰加载下金属柱壳膨胀破裂过程研究. 爆炸与冲击, 2003, 23:529-533

	Experiment	MPM3D with Weibull	MPM3D with Gurson
Fragmentation time (μs)	15.4	15.0	15.5

PF Yang, Y Liu, X Zhang, et al. Simulation of Fragmentation with Material Point Method Based on Gurson Model and Random Failure. ***CMES*** 85(3): 207-236, 2012

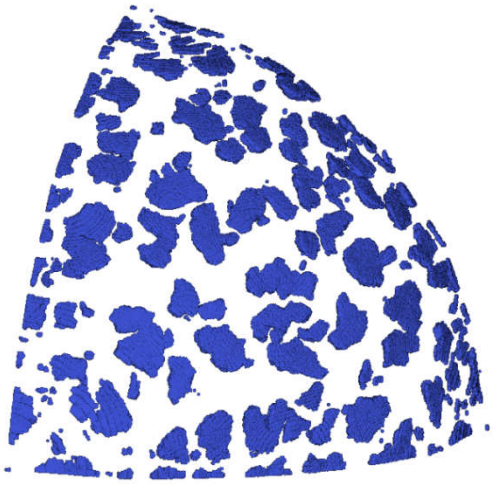
Applications

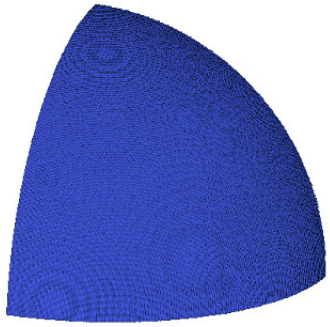
Fragmentation driven by explosion

Weibull random failure

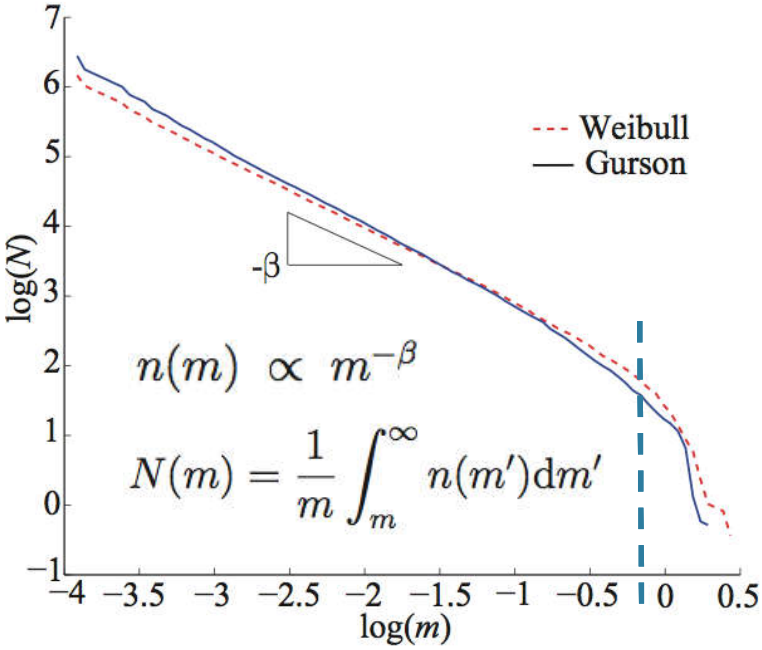


Gurson model





Cumulative mass distribution of fragments



$$n(m) \propto m^{-\beta}$$

$$N(m) = \frac{1}{m}\int_m^{\infty} n(m')\mathrm{d}m'$$

$$\beta_w = 1.06 \quad \beta_g = 1.11$$

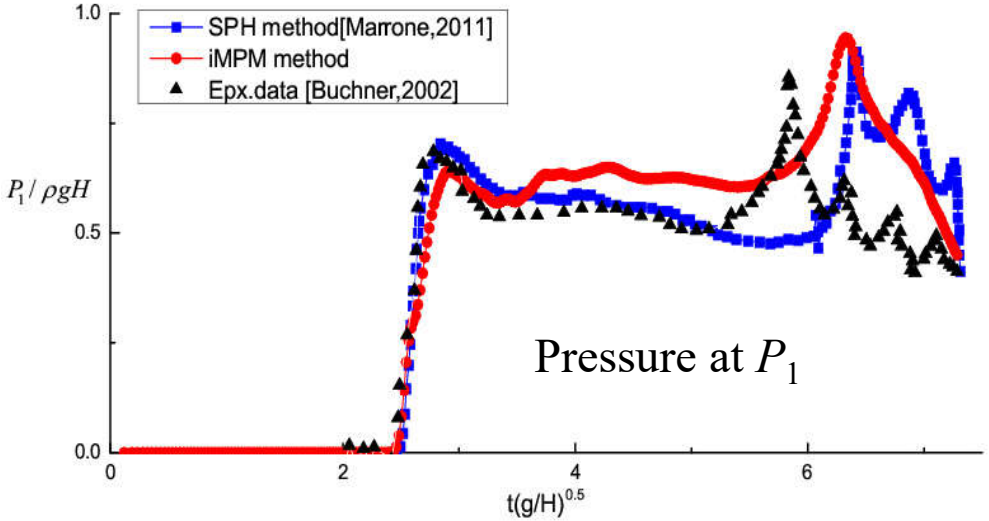
characteristic cutoff mass

$$m_0 = \rho h^3 = 0.4992\mathrm{g}.$$

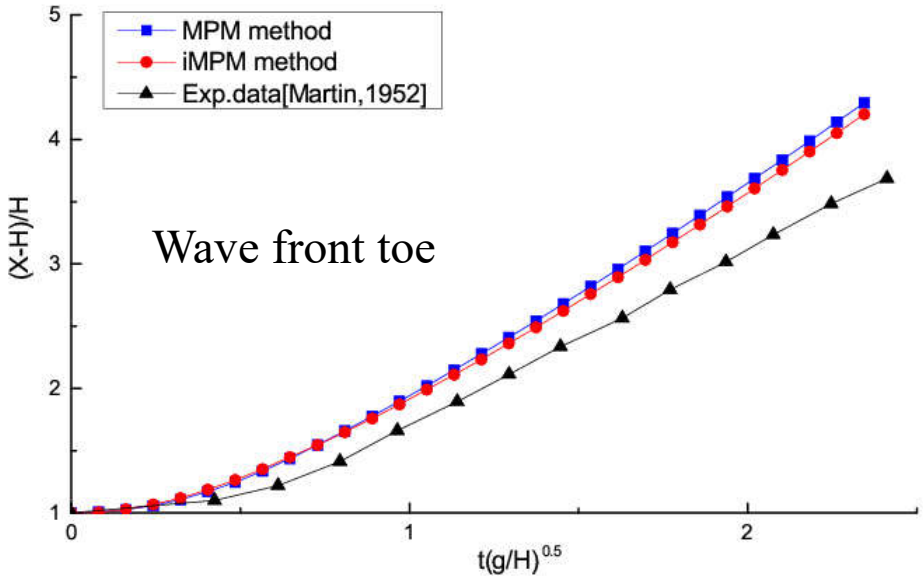
PF Yang, Y Liu, X Zhang, et al. Simulation of Fragmentation with Material Point Method Based on Gurson Model and Random Failure. ***CMES*** 85(3): 207-236, 2012

Applications

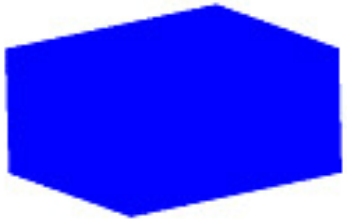
Dam break

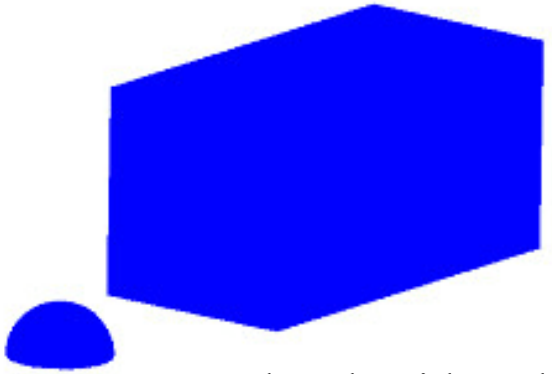


Pressure at P_1



Wave front toe



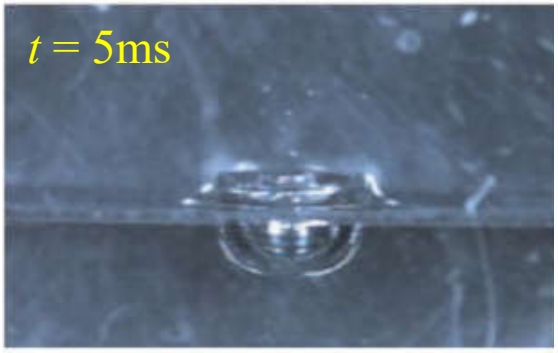


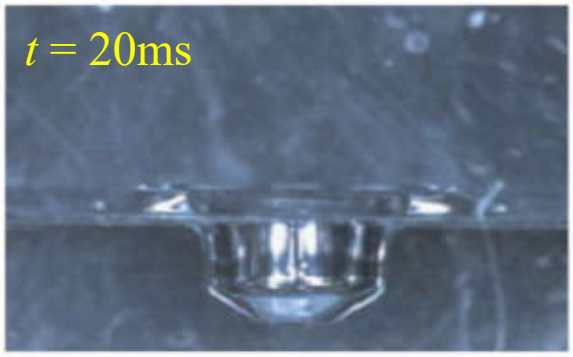
Dam break with a obstacle

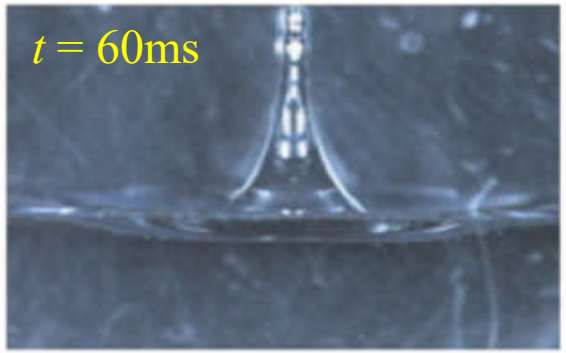
F Zhang, X Zhang, YP Lian, et al. Incompressible material point method for free surface flow. ***Journal of Computational Physics***. To be appeared.

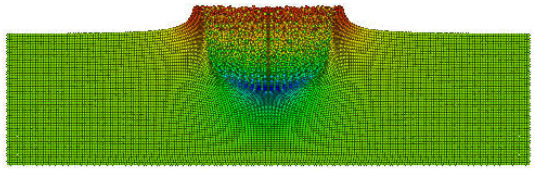
Applications

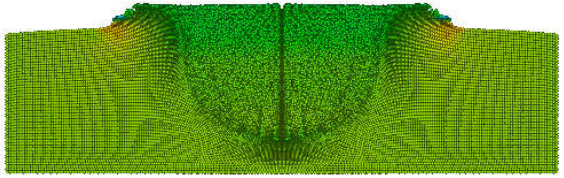
Water droplet impact

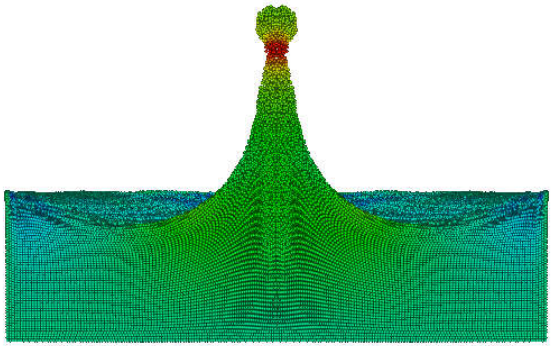


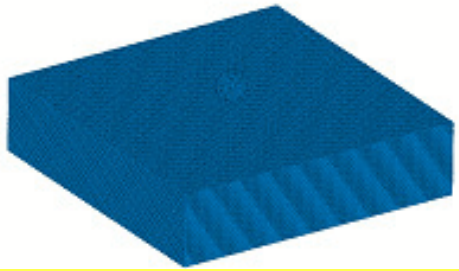


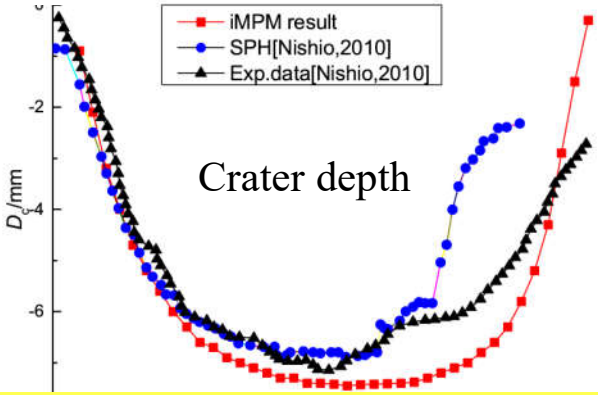








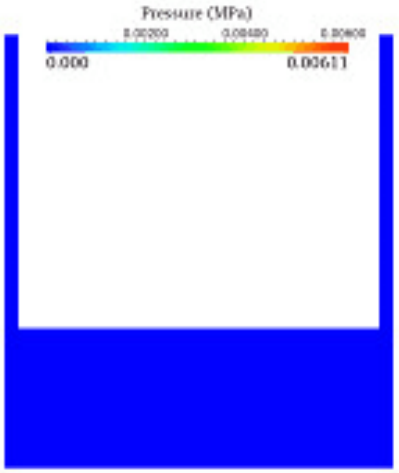




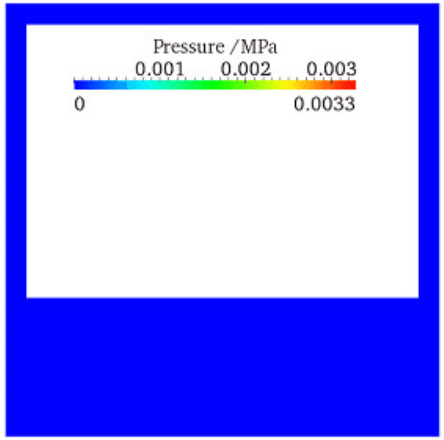
F Zhang, X Zhang, YP Lian, et al. Incompressible material point method for free surface flow. ***Journal of Computational Physics***. To be appeared.

Applications

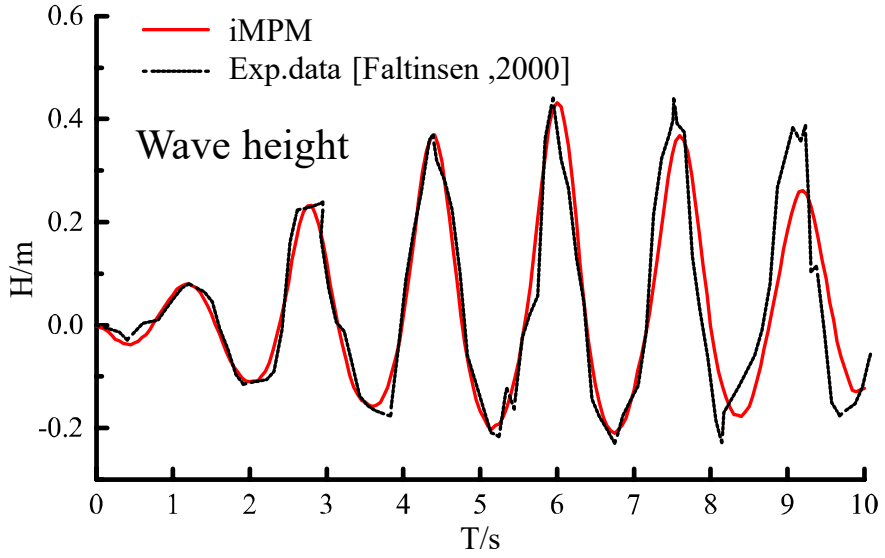
Sloshing due to excitation

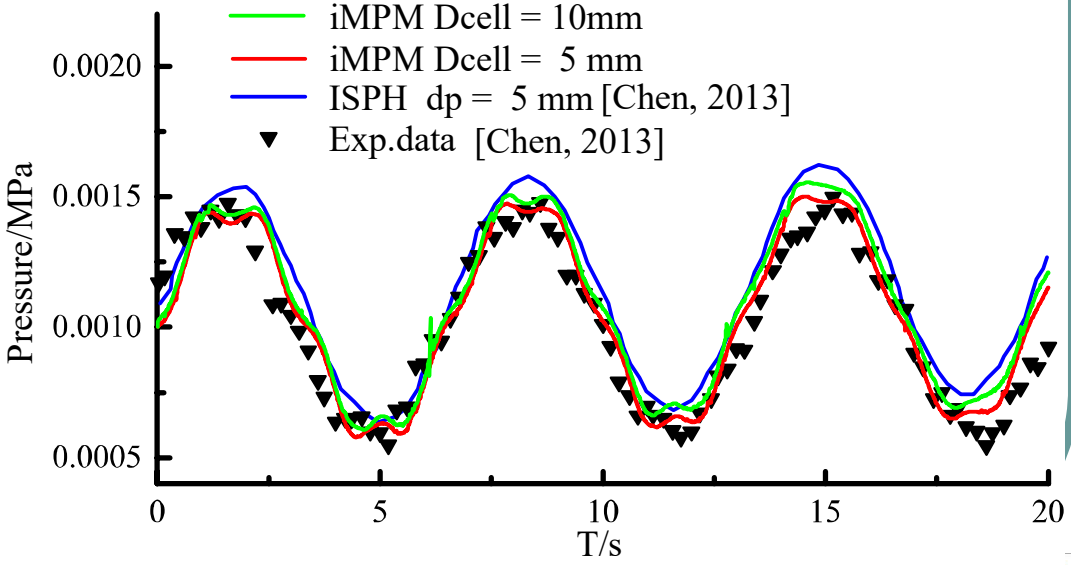


Horizontal excitation



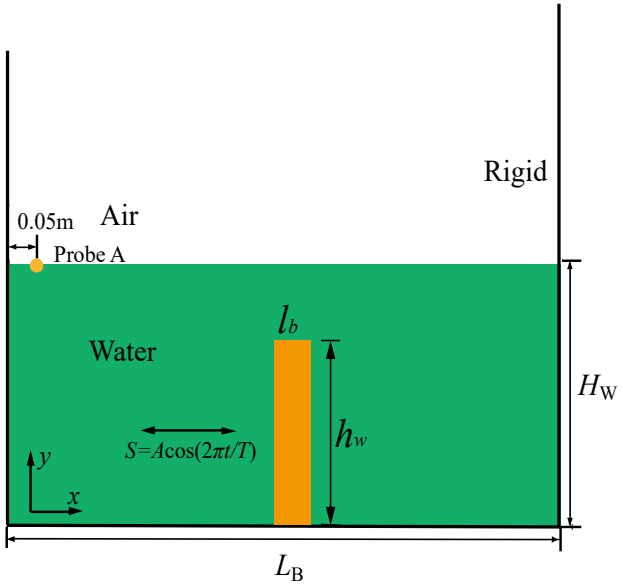
Rolling excitation

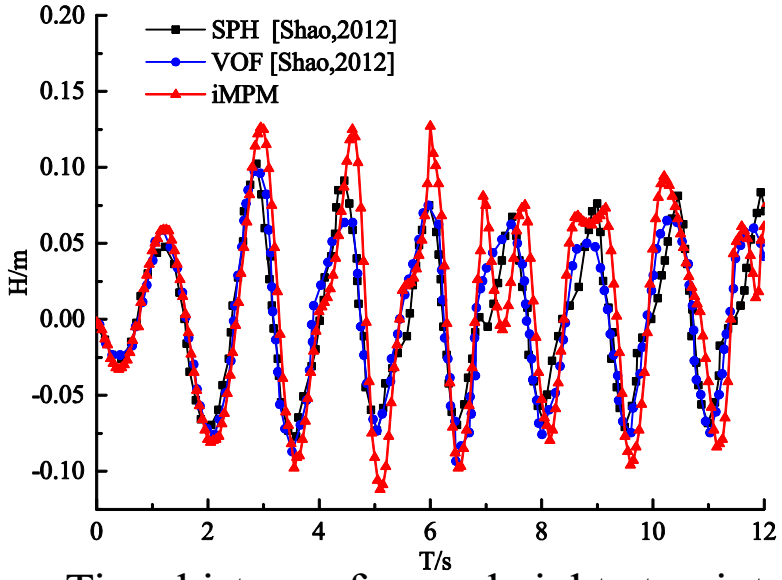




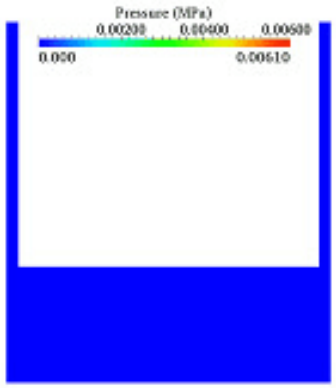
Applications

Sloshing with a middle baffle

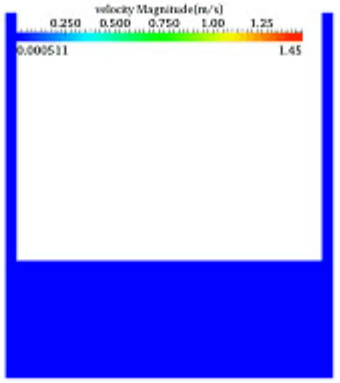




Time history of wave height at point A



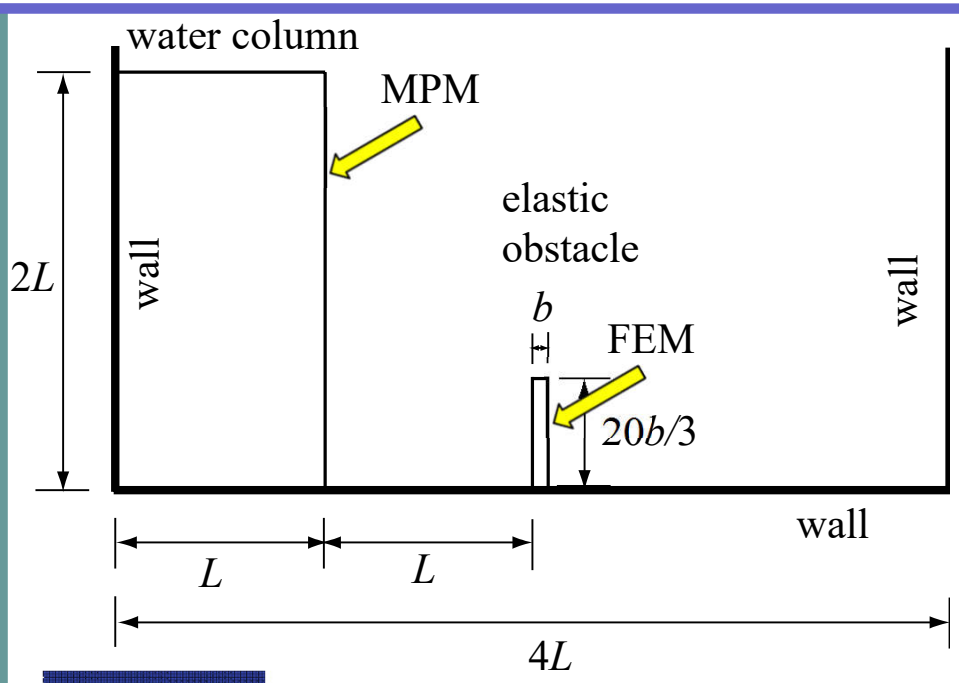
Distribution of pressure

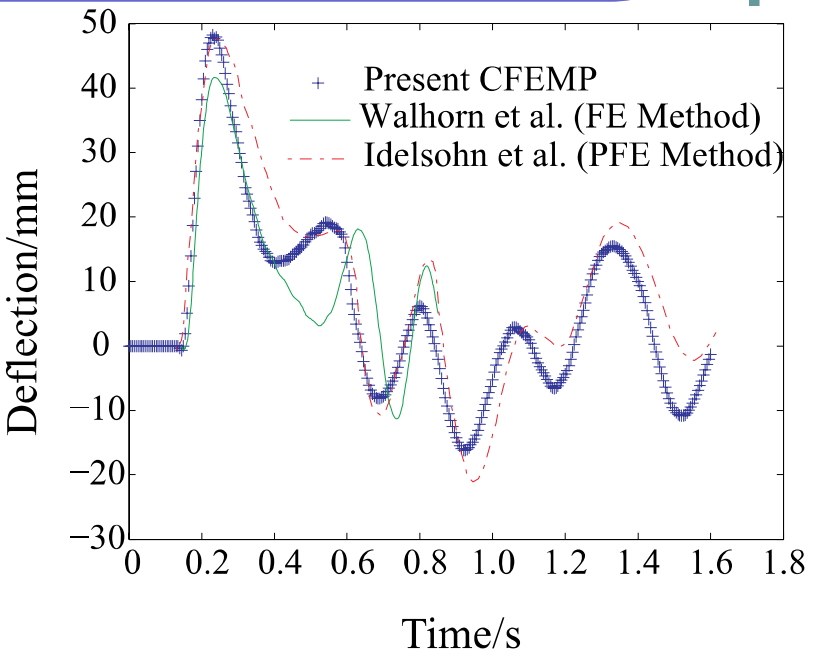


Distribution of velocity

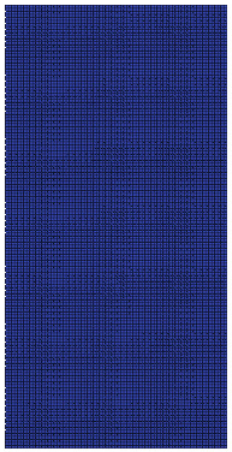
Applications

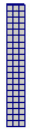
Collapse of water column with a flexible obstacle





Time history of the displacement of the upper left corner of the obstacle





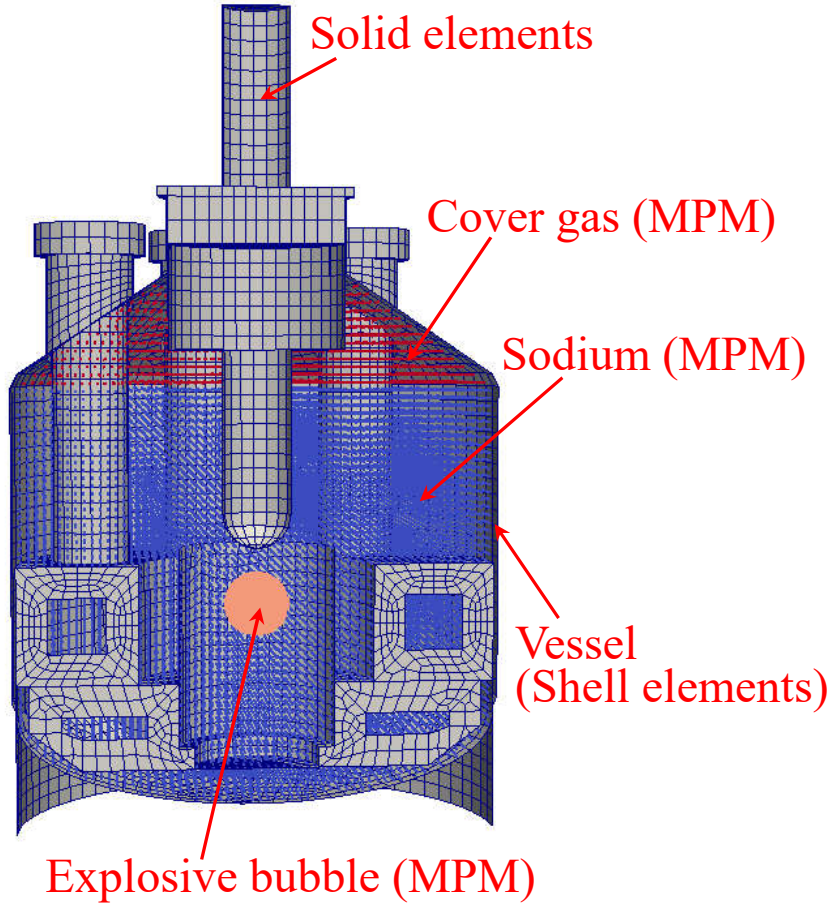
Coupled Finite Element Material Point Method

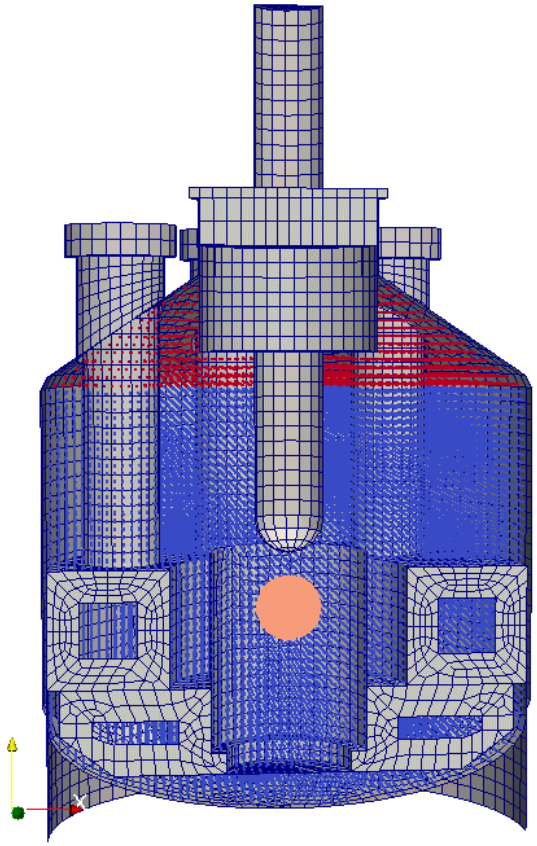
YP Lian, X Zhang, et al. Coupling of finite element method with material point method by local multi-mesh contact method. ***CMAME*** 200: 3482-3494, 2011

Applications

HCDA in a fast reactor

Coupled Finite Element Material Point Method





Hypothetical Core Disruptive Accident in a fast reactor

幻灯片 46

X1	Xiong, 2016/9/21
X2	Xiong, 2016/9/22

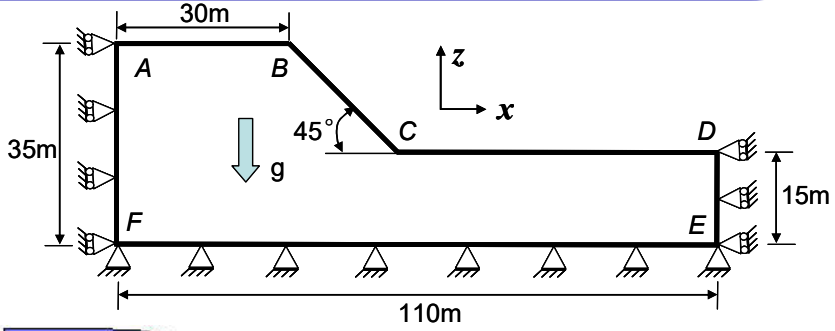
Applications

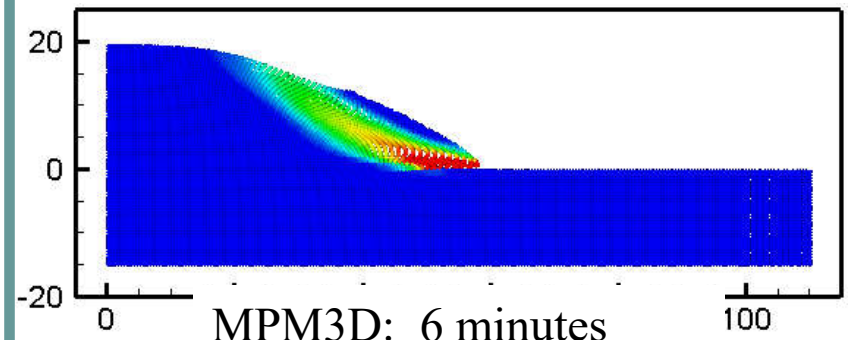
Soil slope failure

- **Cohesive soil**

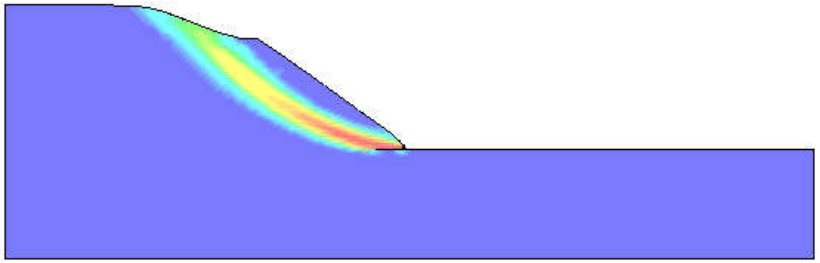
$\phi = 20^o$; $\psi = 0^o$; $c = 10.0$ kPa

E=70MPa, v =0.3, ρ =2.1 g/cm3





MPM3D: 6 minutes



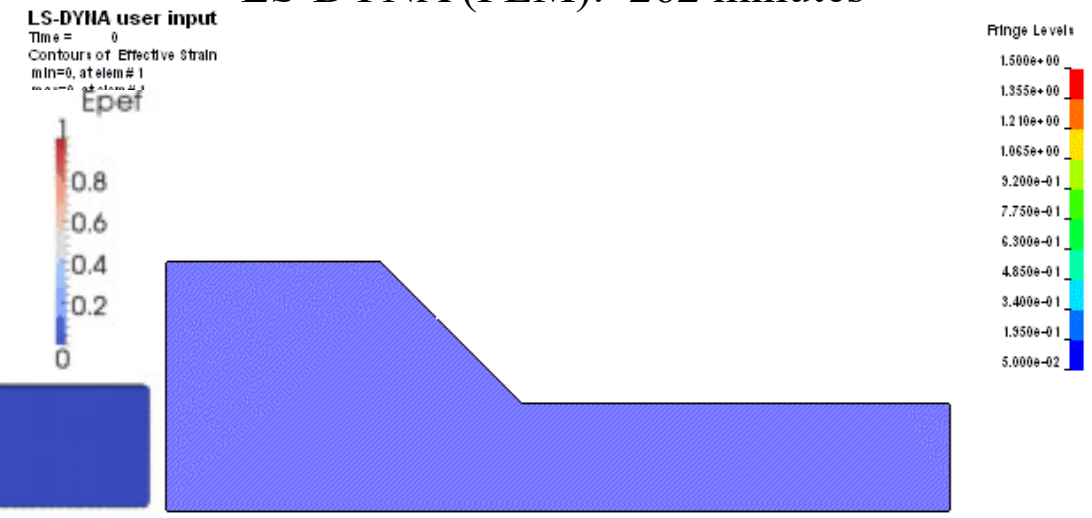
LS-DYNA (FEM): 262 minutes

- **Non-cohesive soil**

$\phi = 20^o$; $c = 0.1$kPa; $\psi = 0^o$



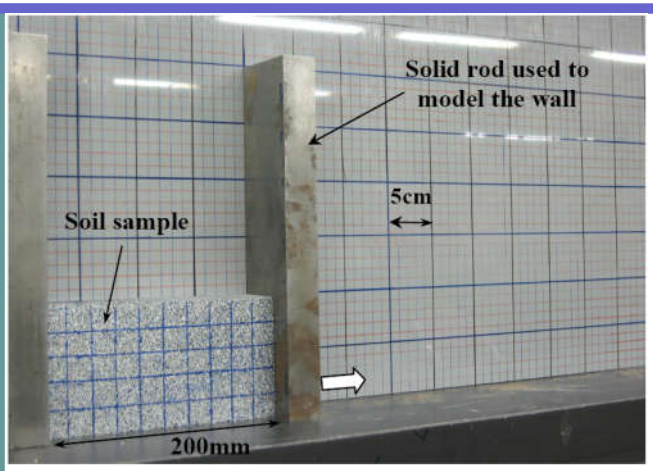
MPM3D: 6 minutes

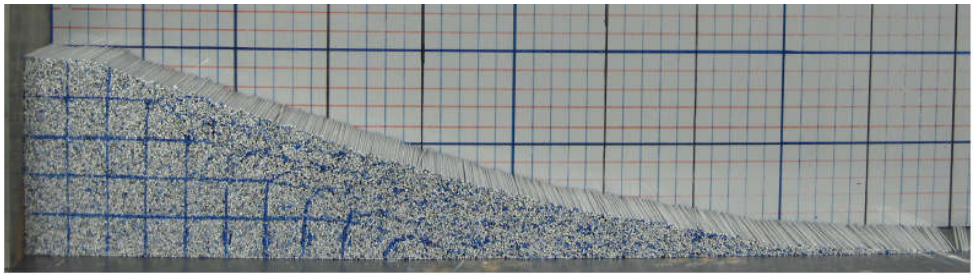


LS-DYNA (FEM): 19.8 hours

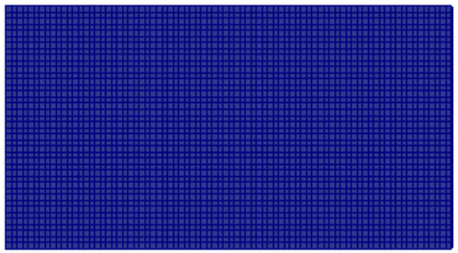
Applications

Failure process of non-cohesive soil





Bui H H, Japan: Ritsumeikan University, 2006

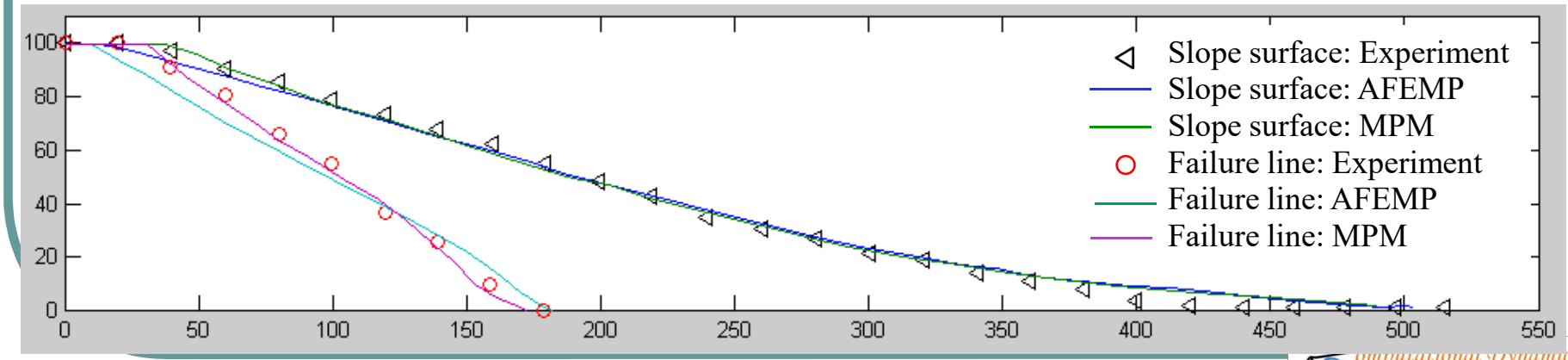


K=0.7MPa，ρ=2.65 g/cm^3

φ = 19.8° ; c = 0kPa;

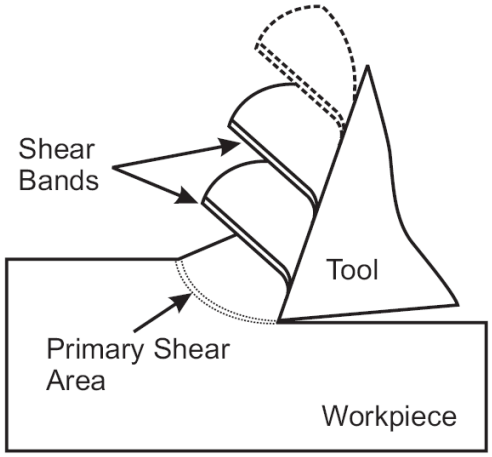
ψ =0°

Adaptive Finite Element Material Point Method



Applications

Metal cutting process





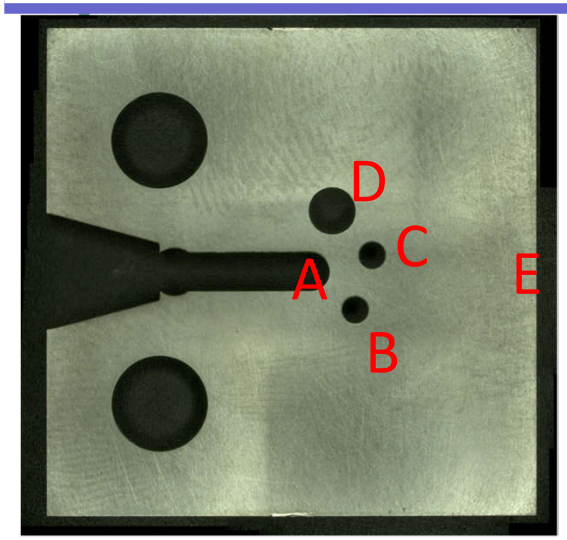




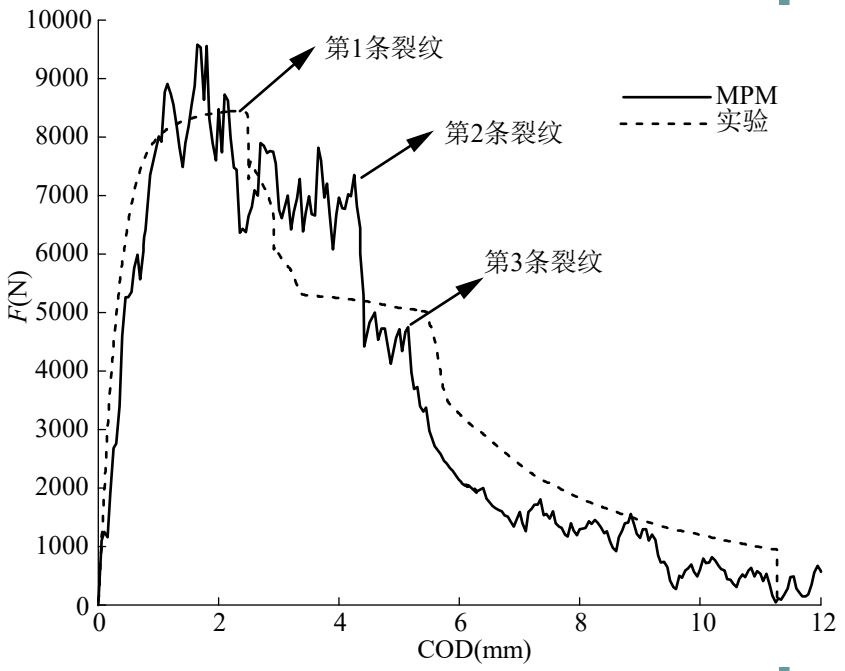
R. Ambati, H Yuan, XF Pan, X Zhang. Application of material point methods for cutting process simulations. ***Computational Materials Science*** 57: 102-110, 2012

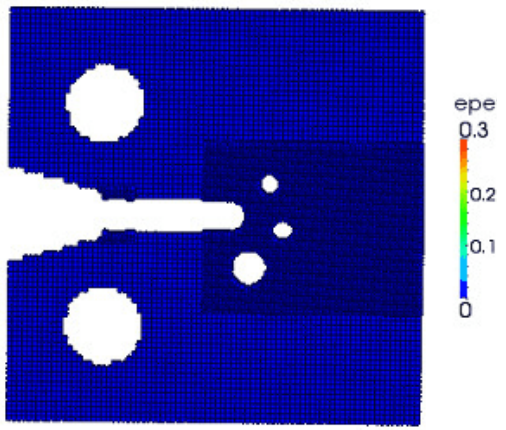
Applications

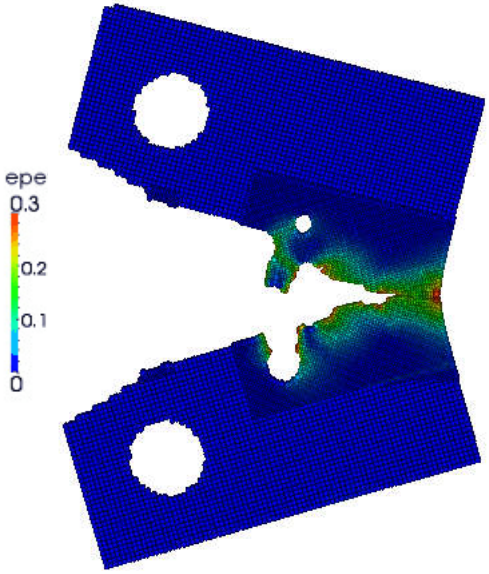
Sandia fracture challenge

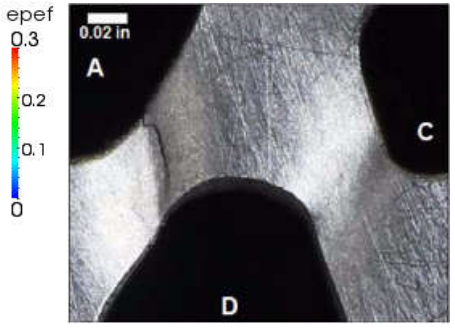


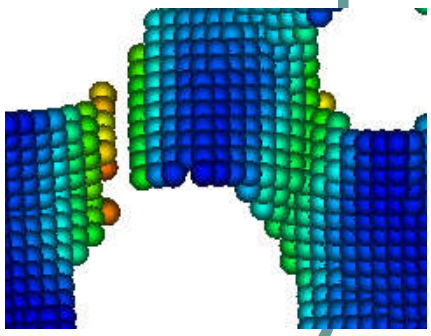










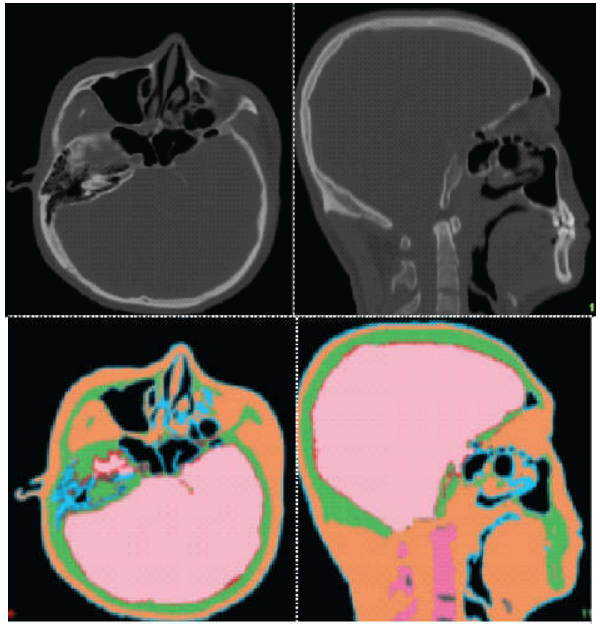


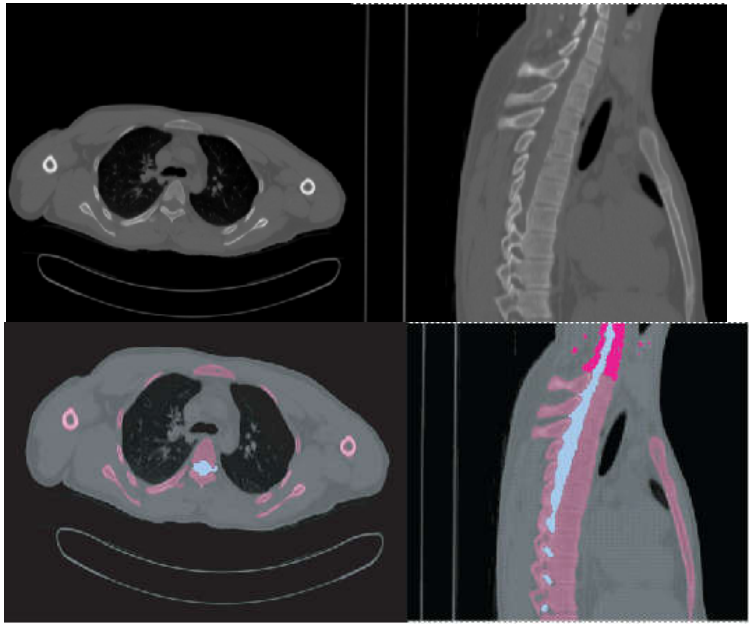
2nd Crack

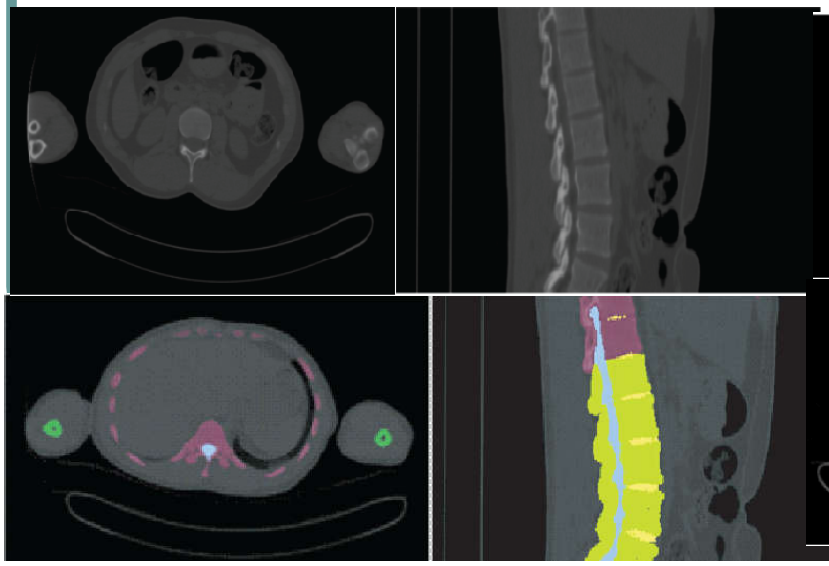
- PF Yang, Y Gan, X Zhang, et al. ***International Journal of Fracture***. 186(1-2): 177-184, 2014
- B. L. Boyce, et al. ***International Journal of Fracture***. 186(1-2): 5-68, 2014

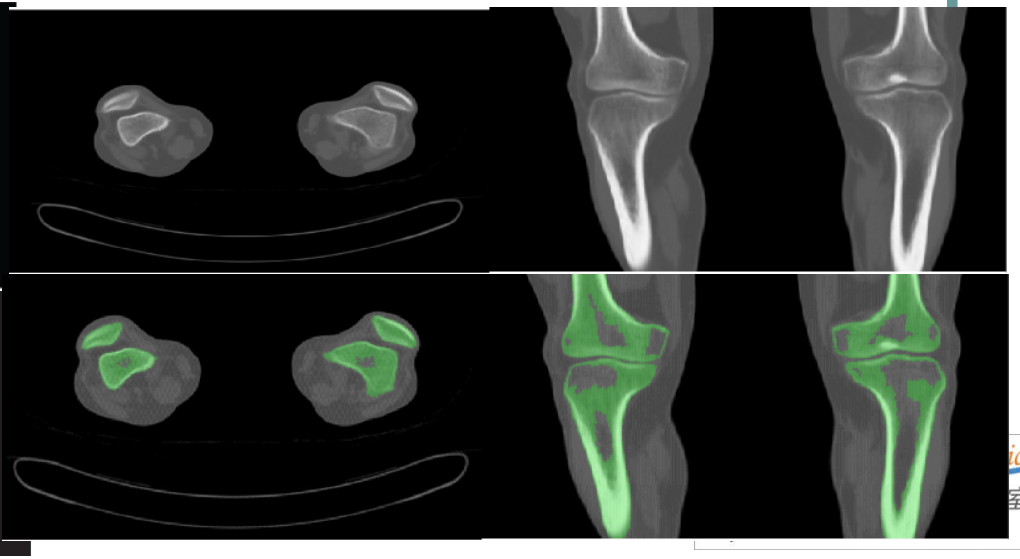
Applications

Biomechanics



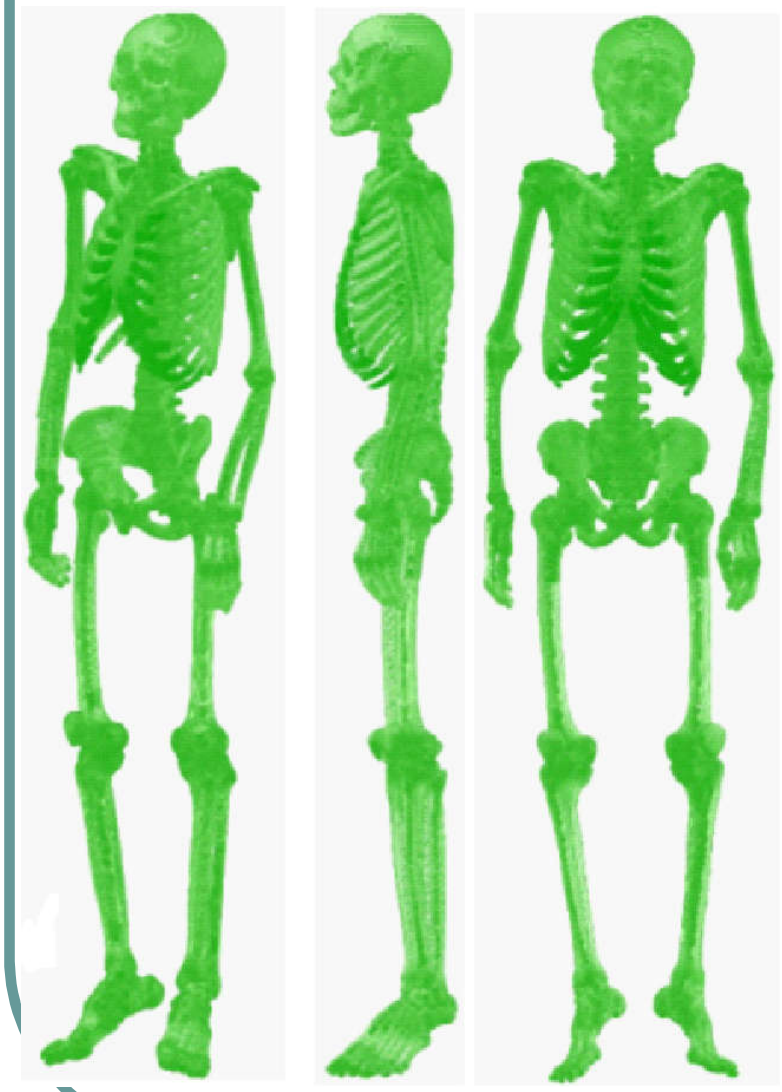




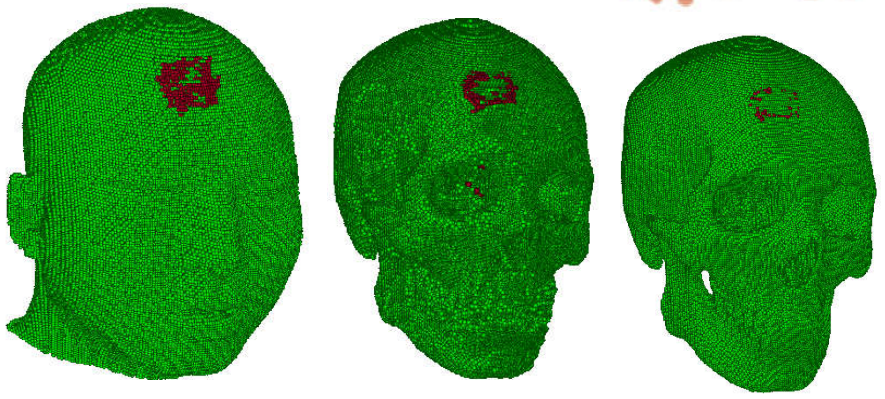


Applications

Biomechanics







Muscle Membrane Skull

SZ Zhou, X Zhang, et al. Numerical Simulation of Human Head Impact Using the Material Point. ***International Journal of Computational Methods***. 10(4), 2013

Outline

- Introduction
- Material Point Method
- Finite Element Material Point Methods
- Applications
- **Concluding remarks**

Concluding Remarks

- Less accurate, less efficient, and more storage usage for small deformation problem
  - Efficient implementation of MPM
  - Parallel computing
  - Combined with FEM
  - Combined with DFM
- Combines the advantages of Lagrangian and Eulerian methods
  - Impact simulation
  - Cutting simulation
  - Crush simulation
  - Blast simulation
- Much easier to generate a MPM particles than FEM mesh
  - Carbon nanotube composite
  - Digital human modeling
- Easy to be coupled with FEM





Thank you for your attention !





space,