Application of SPH to solid mechanics problems

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Overview

• Introduction/Motivation
• In-house SPH code overview
• Fluid-structure interaction
• Solid mechanics - examples
• Solid mechanics - current work
Introduction/Motivation
Introduction/Motivation

- Failure of materials and structures due to transient loading (e.g. impact, crash)
- Simulation tools are not always able to accurately predict behaviour
- SPH has attractive features:
  - Large deformations
  - Lagrangian
  - Treatment of fracture
In-house SPH code overview
In-house SPH code overview

Eulerian and Total Lagrangian kernel formulations
Constitutive models (elastic, elasto-plastic, composites)
Equations of state (Tait, Mie-gruneisen)
Boundary conditions (prescribed displacement, velocity, acceleration)
Body force
Multiple materials
Contact
Subcycling
Coupled to LLNL-Dyna3D FEM solver
Starting Point

Hypervelocity Impact (1997)

Fluid-structure interaction
Fluid-structure interaction

Interested in structural response
Sloshing ESA
Explosive forming
Ditching helicopter/aircraft
Extreme wave Buoy/wave impact
Analysis of Extreme Loading

Applications:
Sloshing

A cylindrical tank (with a hemi-spherical base):
- Partially filled
- Subjected to Constant frequency base excitation.

The measured parameters are:
- Sloshing force (the reaction force at the attachment of the tank support structure to the shaker table),
- Interface force between the tank and the support structure,
- Fluid motion
Sloshing

Constant sweep frequency
Sloshing

Fill Ratio 1 - 0.2m, 1.7335Hz
Wave height, m VS Time, s

Artificial Viscosity – 1.00

Maximum Wave height ~ 0.4006m at time 1.58231s

Region | Water motion
---|---
OA | Sloshing
AB | Transition from Sloshing to Swirling
BC | Initial Swirling
CD | Steady/stabilised Swirling

0A Sloshing
AB Transition from Sloshing to Swirling
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Explosive forming

- Explosive forming
- Main components involved:
  - Explosive Charge
  - Energy Transfer Medium
  - Forming Die + Clamping
  - Workpiece
Explosive forming

single explosive

multi explosive 3

Time = 809.87
Contour of Formability: Mid. Surface
FLD curve: CRLCS (t=1.6 n=0.26, True strain)

Time = 564.99
Contour of Formability: Mid. Surface
FLD curve: CRLCS (t=1.6 n=0.26, True strain)
Low angle water impact

Part of FP7 SMAES project, using guided water impact facility (INSEAN) developed to allow high-velocity, low angle water impact experiments.

- 47 tests on flat & curved thick plates
- 17 tests on metallic and composite deformable plates
- 2 tests on stiffened panel component
Low angle water impact

Structural component (underwater view)
Low angle water impact

Velocity

4° pitch

Strain gauges

10° pitch
Low angle water impact

Cavitation

Aerated water
Solid mechanics examples
Fragmentation

Explosively driven

Mock-Holt Simulation - Standard SPH (Ra
Time = 5.8153e-040
Bird Strike

Ice Impact
Ballistic/Hypervelocity Impact
Machining
Solid mechanics
current work
The work presented forms part of H2020 project EXTREME (grant agreement No 636549) on dynamic loading of composite structures

www.extreme-h2020.eu
Solid mechanics current work

Dynamic loading of composite materials
- Strain softening
- Interaction area damage
- FE-SPH coupling and adaptivity

Applications
- Birdstrike and debris impact on flat panel
- Birdstrike fan, engine cowl, leading edge
- Debris impact on stiffened panel
- Blade-off
Solid mechanics current work

- During FEM simulations of impact on CFRP excessive element deletion can be a problem
Solid mechanics
current work
Non-local properties – strain softening

SPH as Non-local Regularisation Method

\[ \tilde{E}\varepsilon^* = (1 - \omega)E\varepsilon^* \]

Interaction Area Damage

\[ F = \sigma \cdot A \]

Swegle Interaction Area\(^*\)

Force on particle \(i\)

\[
\langle m_i \ddot{u}_i \rangle = \langle F_i \rangle = - \sum_{j=1}^{np} m_i m_j \left( \frac{P_i}{\rho_i^2} + \frac{P_j}{\rho_j^2} \right) \nabla_i W_{ij}
\]

can be rewritten as:

\[
F_i = - \sum_j \left[ P_i \frac{\rho_j}{\rho_i} + P_j \frac{\rho_i}{\rho_j} \right] A_{ij}
\]

with: \( A_{ij} = V_i V_j \nabla_i W_{ij} \)

Interaction Area Damage

Standard approach (Kachanov, Lemaitre) in damage mechanics:

- A damage variable, $D$ represents an effective surface density $\tilde{A}$ due to presence of microscopic cracks or voids within the material

$$\tilde{A} = A (1 - D)$$

- Leads to concept of an effective stress

$$\tilde{\sigma} = \frac{\sigma}{(1 - D)}$$

Interaction Area Damage

- Impact on brittle material modelled with isotropic elastic with failure stress;
Interaction Area Damage
Coupling Algorithms

- Belytschko
- Huerta and Fernandez-Mendez

Domain discretised with a set of particles and a set of FE, where particles are not exactly located at the FE nodes;

Blended shape function methods with higher order reproducibility;

Particle shape functions are modified to improve the quality of the approximation taking into account the interpolation functions and positions of active FE nodes and the particles;

FE shape functions for the non active elements are switched off;

Interpolation space within element replaced by contributions from neighbouring particles and red nodes only;