Modeling Splashing and Sloshing in LS-DYNA using Smoothed Particle Hydrodynamics (SPH)

Erik Svenning, PhD

DYNAmore Nordic

erik.svenning@dynamore.se

Purpose

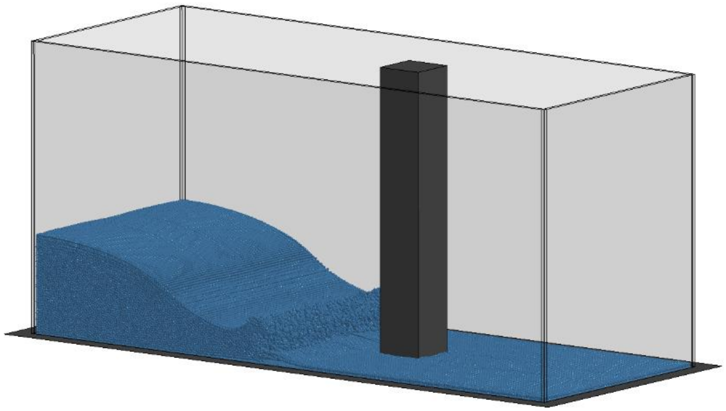
- Demonstrate the capabilities for modeling splashing and sloshing using the Smoothed Particle Hydrodynamics (SPH) module in LS-DYNA

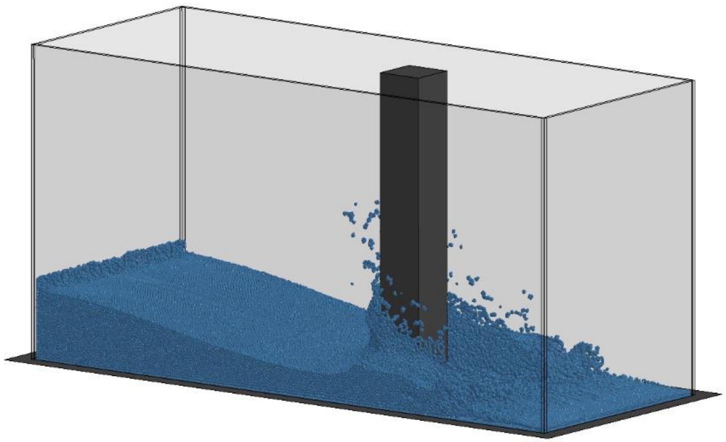
Outline

- Introduction and motivation
- Theory
- Keywords and simulation setup
- Examples
- Summary

Solver introduction - The SPH module in LS-DYNA

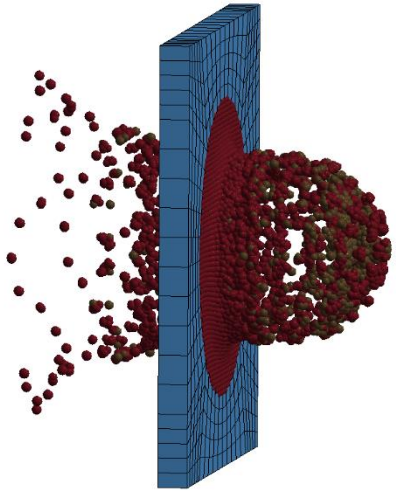
- When is SPH useful?
  - Large material distortion
  - Material decomposes into many small fragments or droplets
  - Moving boundaries and free surfaces
- Characteristics
  - Particle based
  - Explicit
- Issues
  - What about local mesh refinement?
  - Difficult to handle (some) BCs



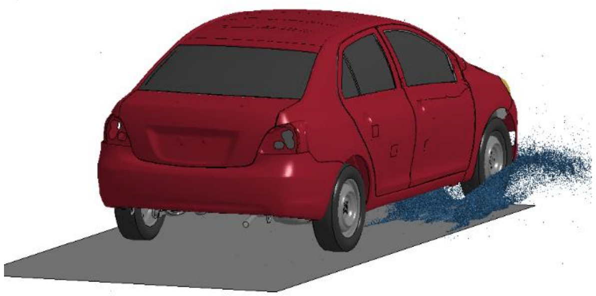


SPH: Smoothed Particle Hydrodynamics

- History of meshfree methods
  - Pioneers: Lucy, Gingold and Monaghan [1977]
  - Fluid mechanics: Monaghan and Benz [1980]
  - Impact problems: Libersky [1993]
  - …

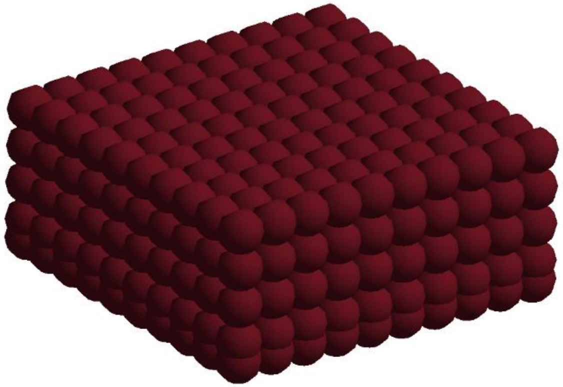


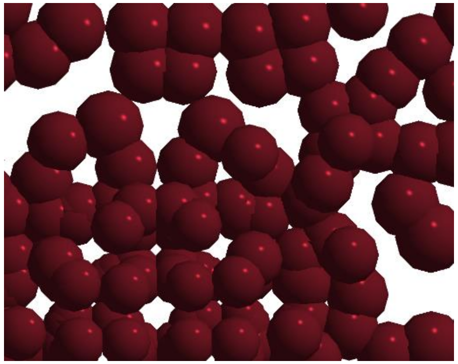
- Applications
  - Forging and extrusion, metal cutting
  - Bird strike
  - High velocity impact
  - Fluid-structure interaction
  - Splashing and sloshing



SPH theory

- Particle based method (mesh free)
  - Continuum approximated by a set of arbitrarily distributed particles
  - Material coordinates are independent variables, no convective term.
  - Allows large material distortion
  - Allows free surface flow
- Particle approximation of a function:
  - $\prod^h f(x) = \int f(y) W(x-y,h) dy$
    - W: Kernel function
    - h: smoothing length
    - Setting $W = \delta(x-y)$, where δ is the Dirac delta, would make the approximation exact
    - The kernel function is constructed such that
      $W \rightarrow \delta$ as $h \rightarrow 0$
    - Cubic b-spline functions are often used





SPH theory

- Quadrature formula:
  - $\prod^h f(x_i) = \sum_{j=1}^{N} w_j f\left(x_j\right) \mathrm{W}(x_i - x_j, \mathrm{h})$
    - w_j: weight of a particle
    - Compact support of W gives a sparse scheme
  - Similarly for the gradient:
    - $\nabla \prod^h f(x) = \int f(y) \nabla W(x-y,h) dy$
- Neighbor search
  - Need to know the neighbors of each particle in order to compute contributions
  - Bucket sort
- Solve for conservation of
  - Mass
  - Momentum
  - Energy

Keywords

- CONTROL_MPP_DECOMPOSITION_DISTRIBUTE_SPH_ELEMENTS
- CONTROL_MPP_IO_NODUMP

- CONTROL_SPH
- SECTION_SPH
- ELEMENT_SPH

- MAT_NULL
- EOS_***

- CONTACT_AUTOMATIC_NODES_TO_SURFACE

Keywords

- CONTROL_MPP_DECOMPOSITION_DISTRIBUTE_SPH_ELEMENTS
  - Ensures that SPH elements are evenly distributed to all processors
    - Balance for the initial positions of the SPH particles
  - No input parameters

- CONTROL_MPP_IO_NODUMP
  - Suppresses the output of all dump files and full deck restart files
  - No input parameters

Keywords

- CONTROL_SPH

NCBS	BOXID	DT	IDIM	NMNEIGH	FORM	START	MAXV
1	0	10^20		150	0	0.0	10^15

CONT	DERIV	INI	ISHOW	IEROD	ICONT	IAVIS	ISYMP
0	0	0	0	0	0	0	100

ITHK	ISTAB	QL					
0	0	0.01					

- NCBS: Number of time steps between particle sorting.
  - Can sometimes be increased to save computational time.
- BOXID: Particles that leave the box are deactivated to save computational time.
  - Should be used.
- IDIM: Space dimension for SPH particles
  - EQ.3: 3D
  - EQ.2: 2D plane strain
  - EQ.-2: 2D axisymmetric

Keywords

- CONTROL_SPH
  - FORM: Particle approximation theory.
    - FORM = 15 or 16 is recommended for fluid applications.
      - Enhanced fluid formulations.
      - Pressure smoothing
      - FORM = 16: with renormalization. Usually more accurate, but also more expensive.
    - Several other particle approximation theories are available.
      - FORM=0 is default.
      - FORM=1 for solid structural applications.
  - MAXV: Particles with a velocity greater than MAXV will be deactivated.
  - ITHK: Contact thickness option.
    - EQ.0: Contact thickness set to zero (default).
    - EQ.1: Contact thickness computed from particle volume.

Keywords

- SECTION_SPH

SECID	CSLH	HMIN	HMAX	SPHINI	DEATH	START	SPHKERN
	1.2	0.2	2.0	0.0	10^20	0.0	0

  - CSLH: Constant for calculation of initial smoothing length. The default value works for most problems.
  - HMIN and HMAX: Scale factors for minimum and maximum smoothing length.

- ELEMENT_SPH

NID	PID	MASS	NEND				

  - MASS
    - GT.0: Mass value
    - LT.0: The absolute value will be used as volume. The density is taken from the material card defined in PID.

Keywords

- Fluid material properties specified with MAT_NULL and a suitable EOS

  - MAT_NULL

MID	RO	PC	MU	TEROD	CEROD	YM	PR
		0.0	0.0	0.0	0.0	0.0	0.0

- RO: Mass density

- PC: Pressure cut-off
  - Allows a material to ”numerically” cavitate.
  - Pressure cut-off is negative in tension.

- MU: Dynamic viscosity

- TEROD: Relative volume V/V_0 for erosion in tension.
- CEROD: Relative volume V/V_0 for erosion in compression.

Keywords

- EOS: Equation of State
  - Describes the relation between density and pressure

- EOS_MURNAGHAN

EOSID	GAMMA	K0	V0				

$$p = k_0 \left[\left(\frac{\rho}{\rho_0} \right)^{\gamma} - 1 \right]$$

  - Designed to model incompressible fluid flow with SPH elements.
  - GAMMA is often set to 7.
  - K0 is chosen such that C0 = sqrt(GAMMA*K0/RHO0) >= 10v_max, where v_max is the maximum expected fluid flow velocity
  - V0: Initial relative volume
  - Reducing the stiffness of the SPH particles allows larger time steps at the cost of increased compressibility.

- EOS_GRUNEISEN
  - Can be an alternative

Keywords

- CONTACT_AUTOMATIC_NODES_TO_SURFACE

SSID	MSID	SSTYP	MSTYP	SBOXID	MBOXID	SPR	MPR

FS	FD	DC	VC	VDC	PENCHK	BT	DT

SFS	SFM	SST	MST	SFST	SFMT	FSF	VSF

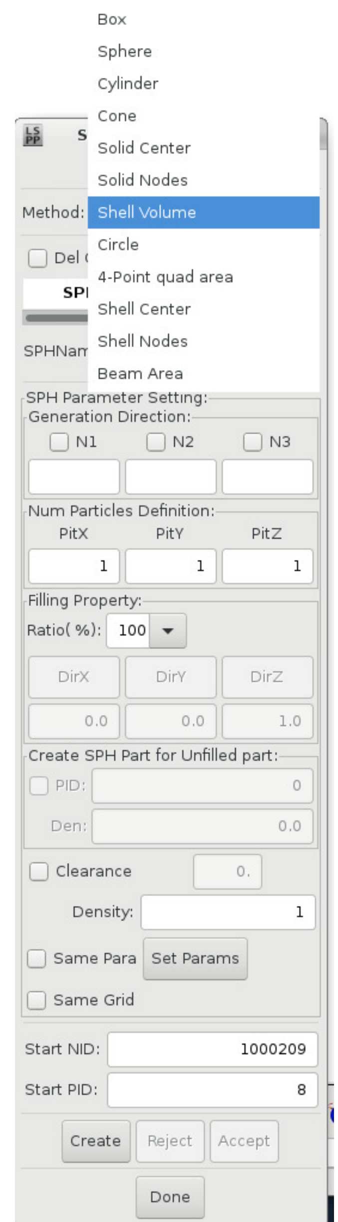
  - Contact for interaction between SPH particles and structure
  - SSID: Slave set ID -> SPH particles
  - MSID: Master set ID -> Structure

Generation of SPH elements in LS-PrePost

- Mesh -> SphGen

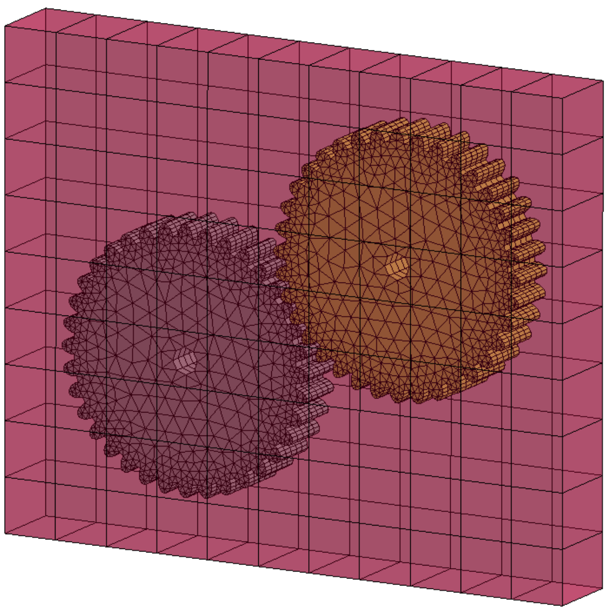
- SPH parts of different shape
  - Simple shapes (Box, sphere,…)
  - Solid center
  - Solid nodes
  - **Shell volume**
  - Shell Center
  - Shell nodes
  - …

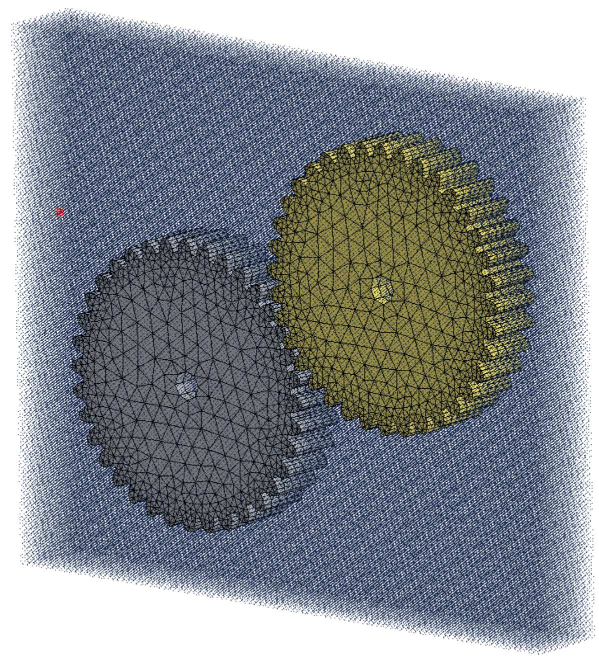
- Set Density to -1 to make LSPP compute the volume of each SPH particle
- PitX, PitY, PitZ
  - Distance between particles in each direction
- Click Set Params to apply settings

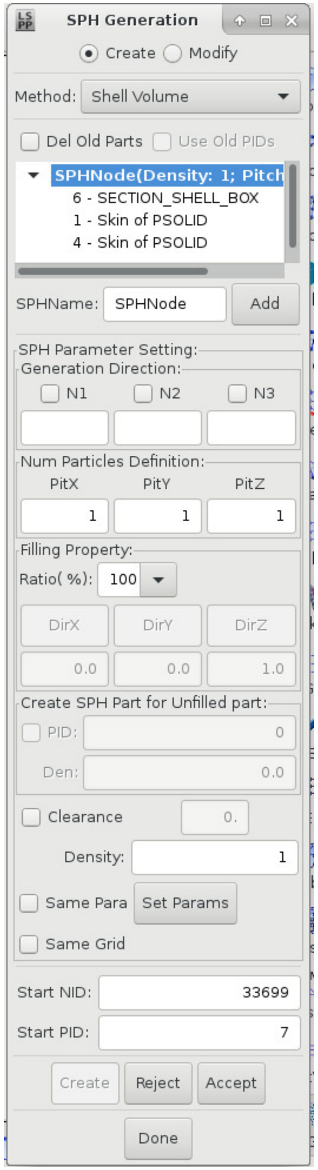


Generation of SPH elements in LS-PrePost

- Example: SPH generation for simplified gearbox
  - Method: Shell Volume
  - Surface shell mesh needs to be water tight
  - The surface may consist of several parts as in this example

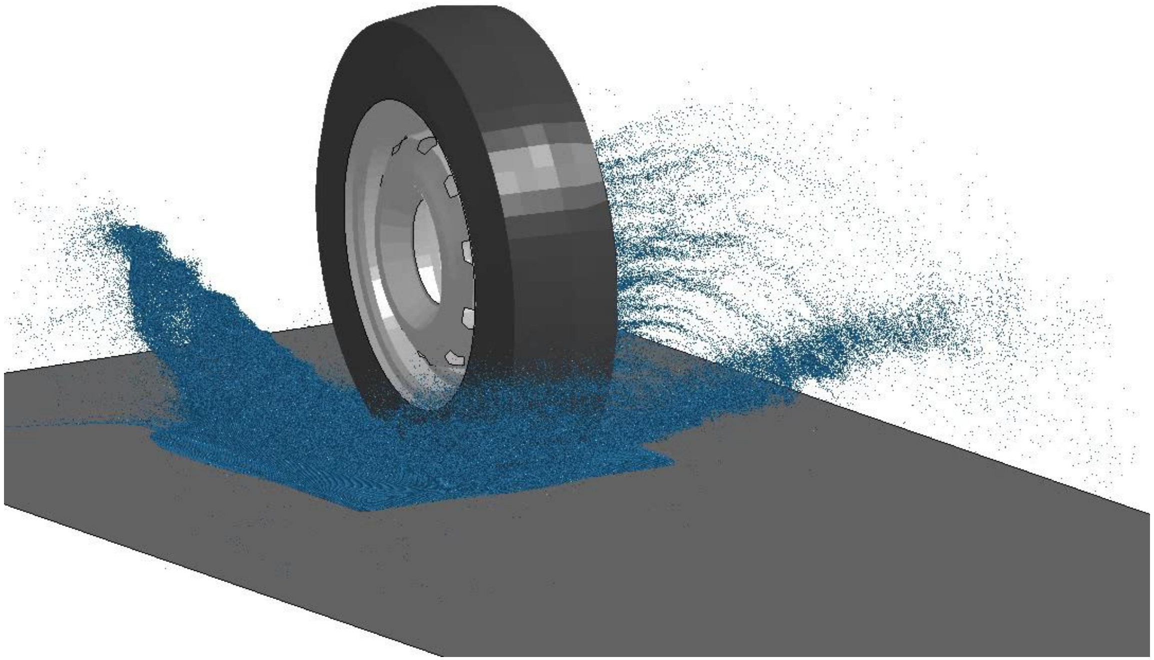






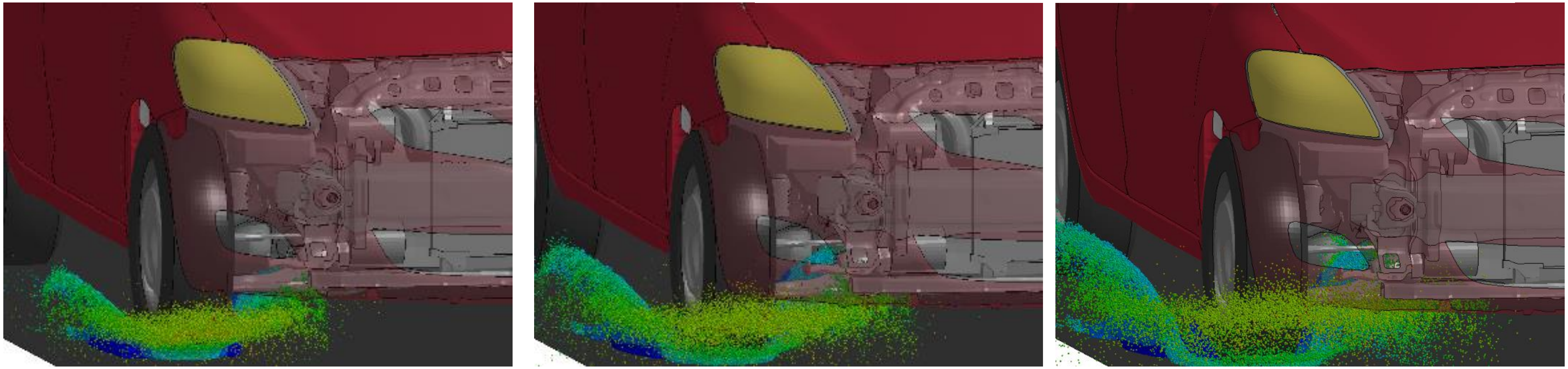
Example 1: Wheel water splashing

- A wheel rolls through a 10 mm thick water layer at 70 km/h
  - Explicit FE with deformable tire
  - Rigid rim
  - Rigid ground
  - SPH model for the water
    - 600 × 400 × 10 mm
    - 2.4M SPH particles



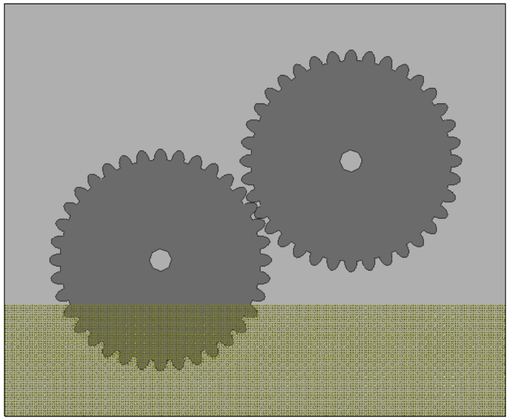
Example 2: Full car water splashing

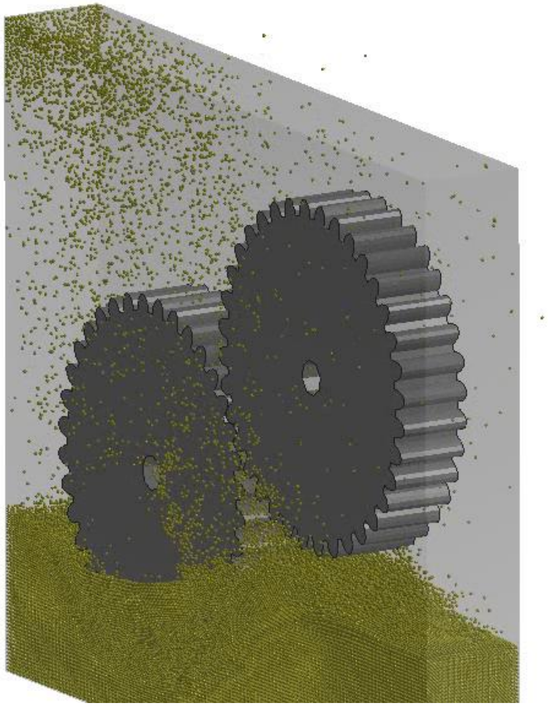
- NHTSA Toyota Yaris model
  - Explicit FE
  - 1.5M elements
  - 56 km/h
- 20 mm thick water layer
  - 300k SPH particles
- Possible output
  - Distribution of water
  - Water load on different parts
- Simulation time: 16h on 32 cores



Example 3: Oil splash in simplified gearbox

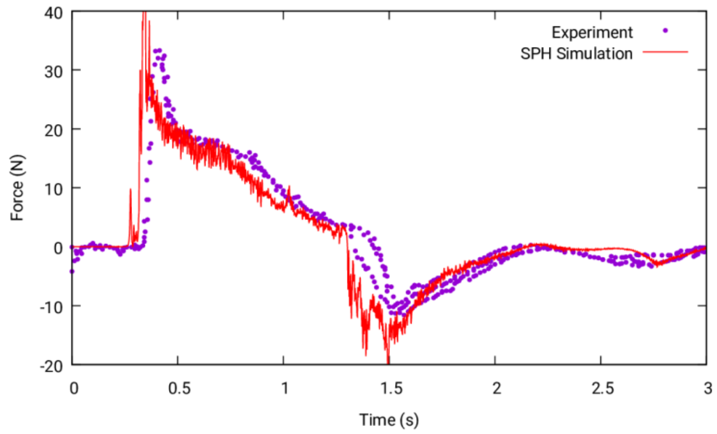
- Two gears in a box partially filled with oil
  - Rigid gears
  - Oil: 300k SPH particles
- Prescribed motion of the upper gear
  - Ramped up to 1000 rpm
  - Upper gear drives the lower gear through contact conditions
  - It is possible to model the gears as deformable (at the cost of longer simulation time)
- Oil properties
  - Density 900 kg/m^3
  - Viscosity 10 mPas
  - Equation of state: Gruneisen with C = 150 m/s
- Simulation time:
  - **3 hours** on **16 cores**

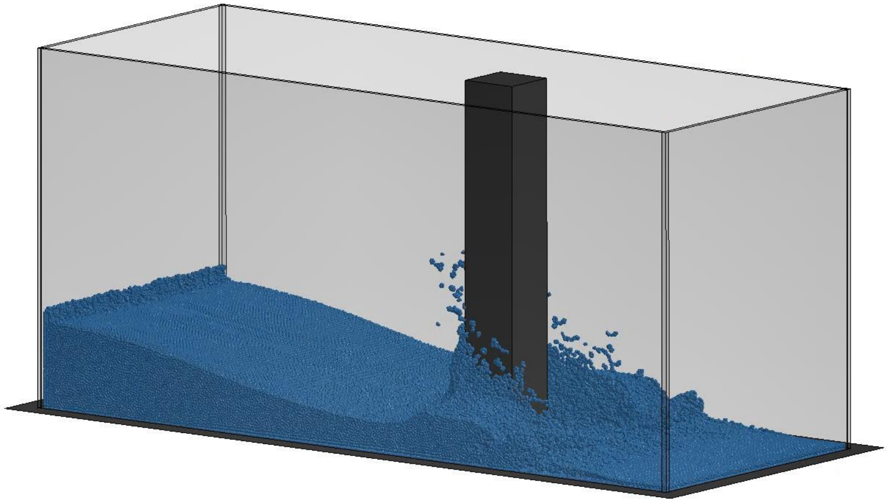




Example 4: Wave-Structure Interaction

- A wave impacts a rigid column in a container
  - Total contact forces compared to experimental data
  - Model developed by LSTC. Available at www.dynaexamples.com/sph/intermediate-examples/wavestructure





Summary

- In this webinar, we have discussed how SPH can be used to model splashing and sloshing
- Easy to couple SPH with finite element models

- If you want to learn more:
  - SPH course offered by DYNAmore GmbH: https://www.dynamore.de/en/training/seminars

- Questions and comments
  - erik.svenning@dynamore.se

Thank you!

Your LS-DYNA distributor and more