Integrating DualSPHysics and Chrono with DSPHChronoLib

Iván Martínez-Estévez

Outline

Project Chrono

Coupling SPH-Chrono

Coupling SPH-FEA

Compiling DualSPHysics-Chrono

XML configuration

FSI in DualSPHysics

Outline

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Project Chrono

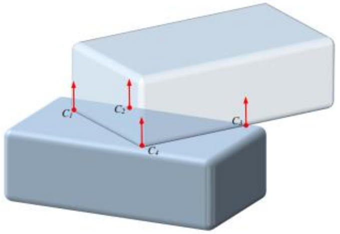
Open-source **multi-physics** simulation engine.

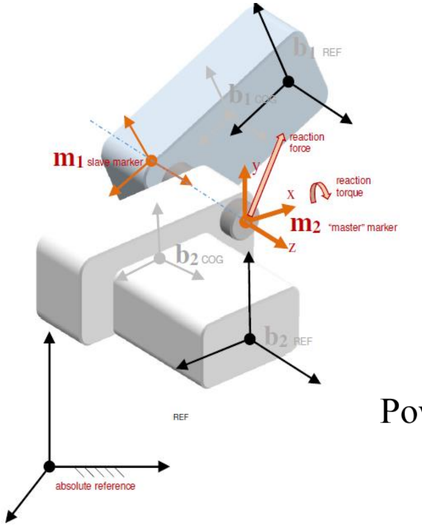
Tasora et al. (2016)

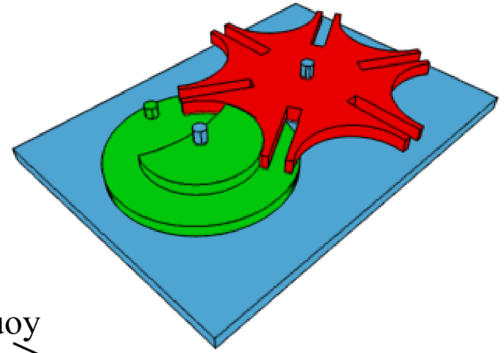
https://projectchrono.org/

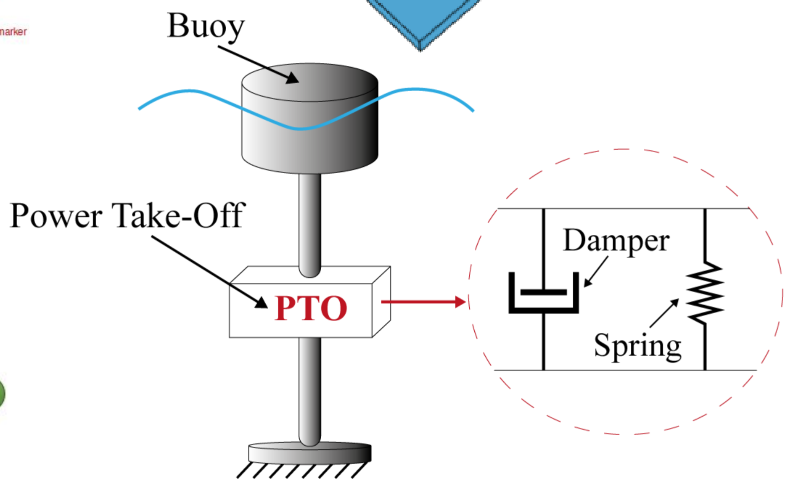
Rigid body dynamics

Compute frictional contact forces.
Collision detection algorithms.
Define surface properties.







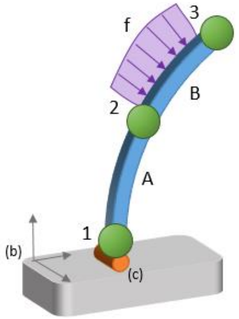


Multi-body dynamics

Mechanical constraints between rigid and flexible objects.
Add motors, linear actuators, springs and dampers.
Apply forces and torques.

Flexible structure dynamics

Use the FEA module to create finite elements and model flexible parts.
Beams, cables, shells, solid tetrahedrons and hexahedrons.

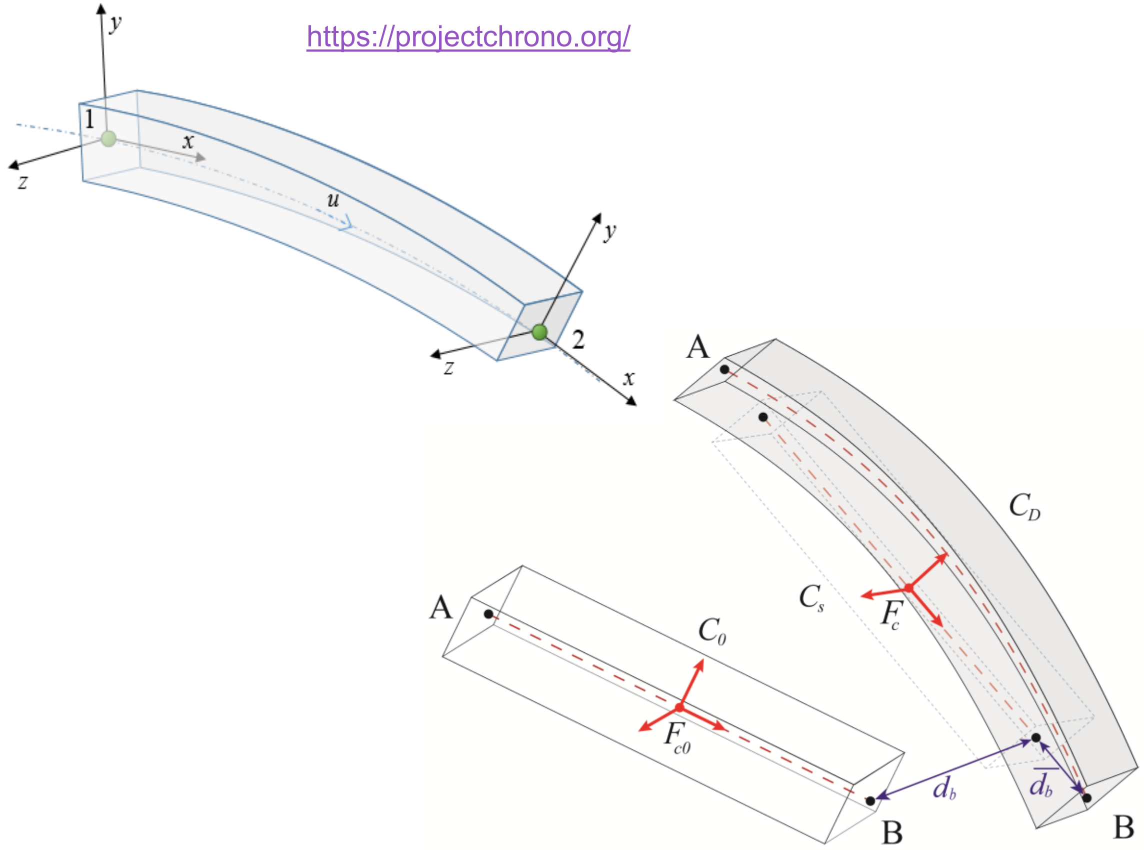


Tasora et al. (2016). **Chrono: An Open Source Multi-physics Dynamics Engine**. High Performance Computing in Science and Engineering. https://doi.org/10.1007/978-3-319-40361-8_2

Project Chrono

Flexible structure dynamics

https://projectchrono.org/



Finite Element Analysis (**FEA**) for structure.

Based on the 3-D Euler-Bernoulli theory.

Corotational formulation.

Large rotations and displacements.

Damping can be defined for the beam element.

Tasora et al. (2016). **Chrono: An Open Source Multi-physics Dynamics Engine**. High Performance Computing in Science and Engineering. https://doi.org/10.1007/978-3-319-40361-8_2

Martínez-Estévez et al. (2023b). **Coupling an SPH-based solver with an FEA structural solver to simulate free surface flows interacting with flexible structures.** Computer Methods in Applied Mechanics and Engineering, 410, 115989. https://doi.org/10.1016/j.cma.2023.115989

Outline

Coupling SPH-Chrono

Reference journal paper

Contents lists available at ScienceDirect

Computer Physics Communications

journal homepage: www.elsevier.com/locate/cpc

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COMPUTER PHYSICS COMMUNICATIONS

Coupling of an SPH-based solver with a multiphysics library ☆,☆☆

Check for updates

I. Martínez-Estévez [a,*], J.M. Domínguez [a], B. Tagliafierro [b], R.B. Canelas [c], O. García-Feal [a], A.J.C. Crespo [a], M. Gómez-Gesteira [a]

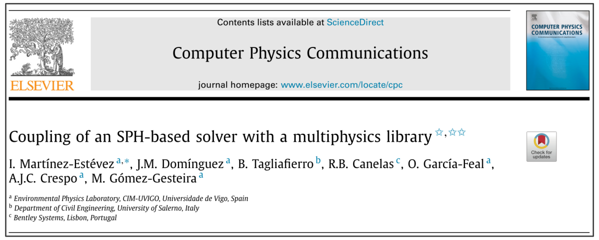
[a] *Environmental Physics Laboratory, CIM-UVIGO, Universidade de Vigo, Spain*
[b] *Department of Civil Engineering, University of Salerno, Italy*
[c] *Bentley Systems, Lisbon, Portugal*

Citations in Scopus: **66**

Martínez-Estévez, I., Domínguez, J. M., Tagliafierro, B., Canelas, R. B., García-Feal, O., Crespo, A. J. C., & Gómez-Gesteira, M. (**2023a**). **Coupling of an SPH-based solver with a multiphysics library**. *Computer Physics Communications*, *283*, 108581. https://doi.org/10.1016/j.cpc.2022.108581

Coupling SPH-Chrono

Software components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DualSPHysics (cpu, gpu)

- Discretises the domain into particles
- Solves the fluid
- Solves the fluid-solid interaction

DSPHChronoLib

- Dynamic library (.dll / .so)
- Controls the communication process
- Handles the information transfer
- Abstraction: only changes in DSPHChronoLib

Project Chrono

- Dynamic library (.dll / .so)
- Solves the mechanical constraints
- Solves solid-solid interaction
- Solves the flexible structure

LGPL Free Software https://github.com/DualSPHysics/DSPHChronoLib.git

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Coupling an SPH-based solver with an FEA structural solver to simulate free surface flows interacting with flexible structures

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Coupling SPH-FEA

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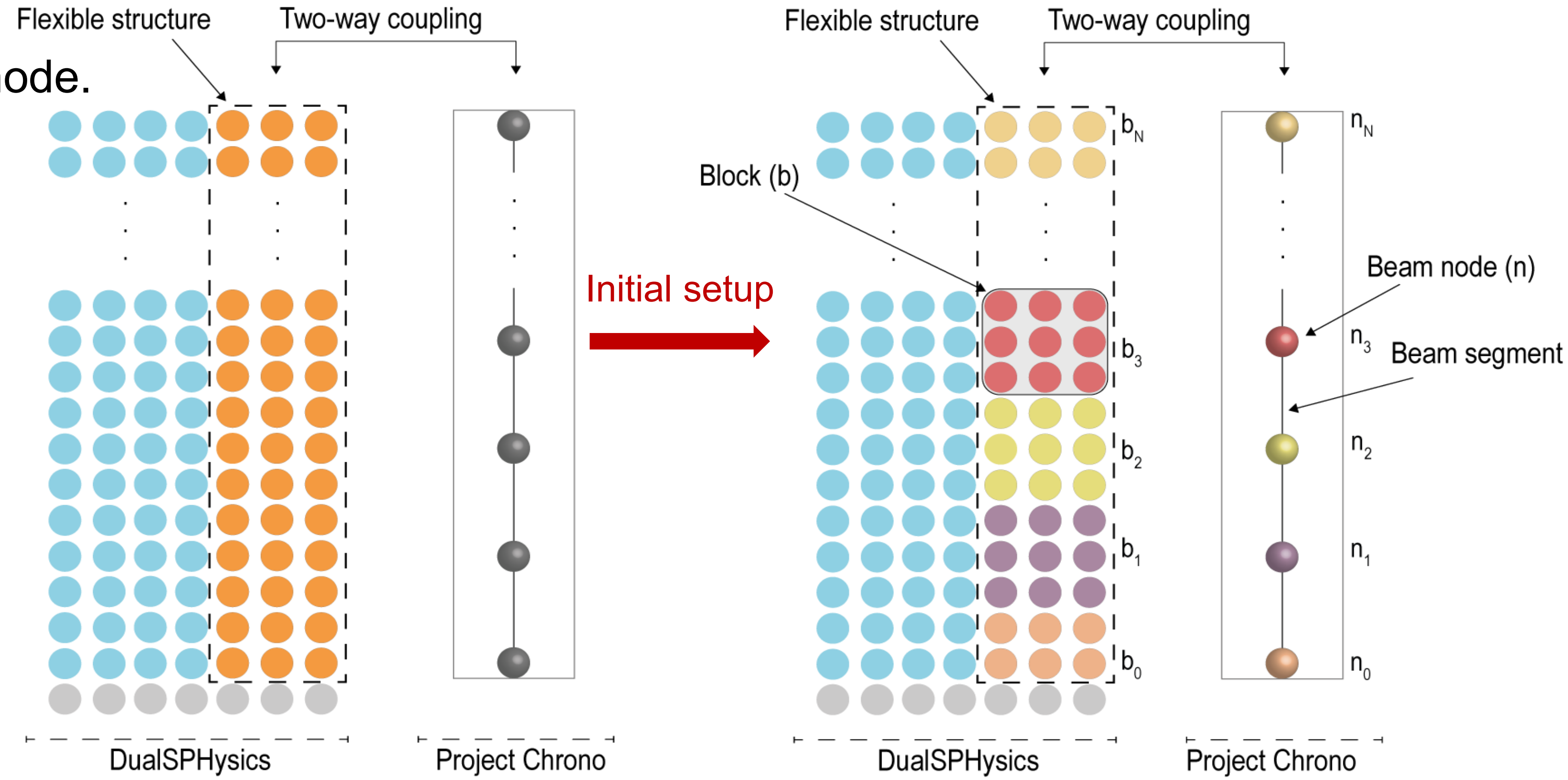
Initial setup

- SPH discretises both: fluid and structure.
- Structure is divided into blocks in SPH.
- A block is a set of particles.
- Each block is assigned to a beam node.



Coupling SPH-FEA

Fluid-structure interaction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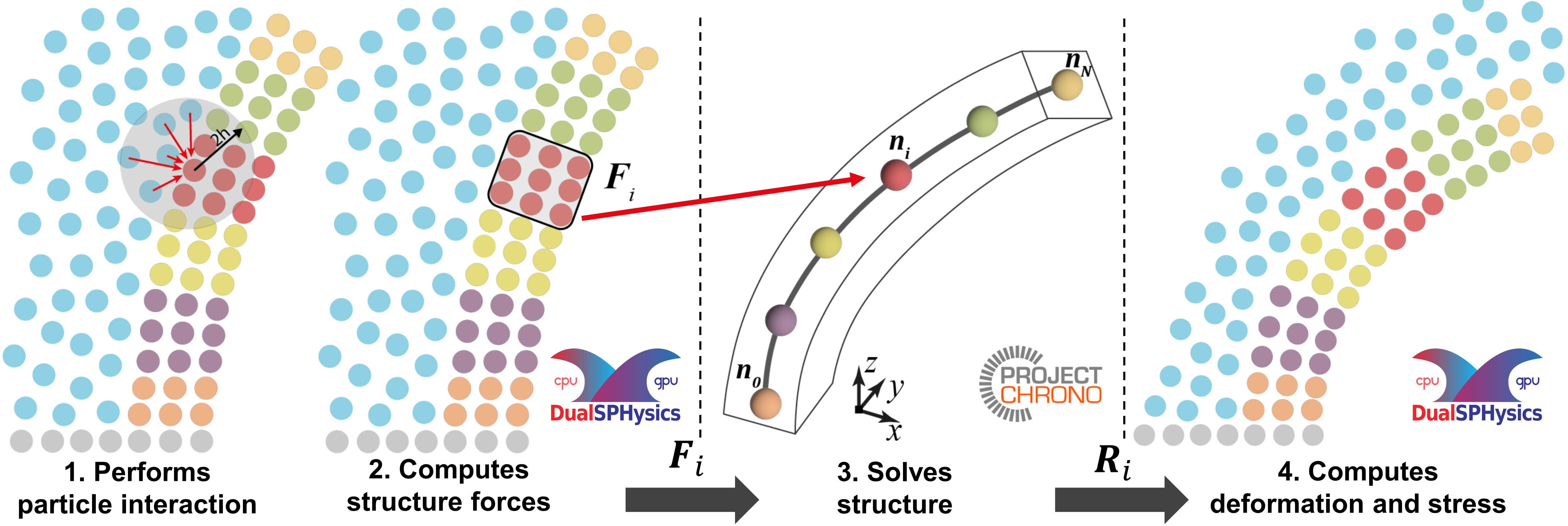

Coupling SPH-FEA

Validation


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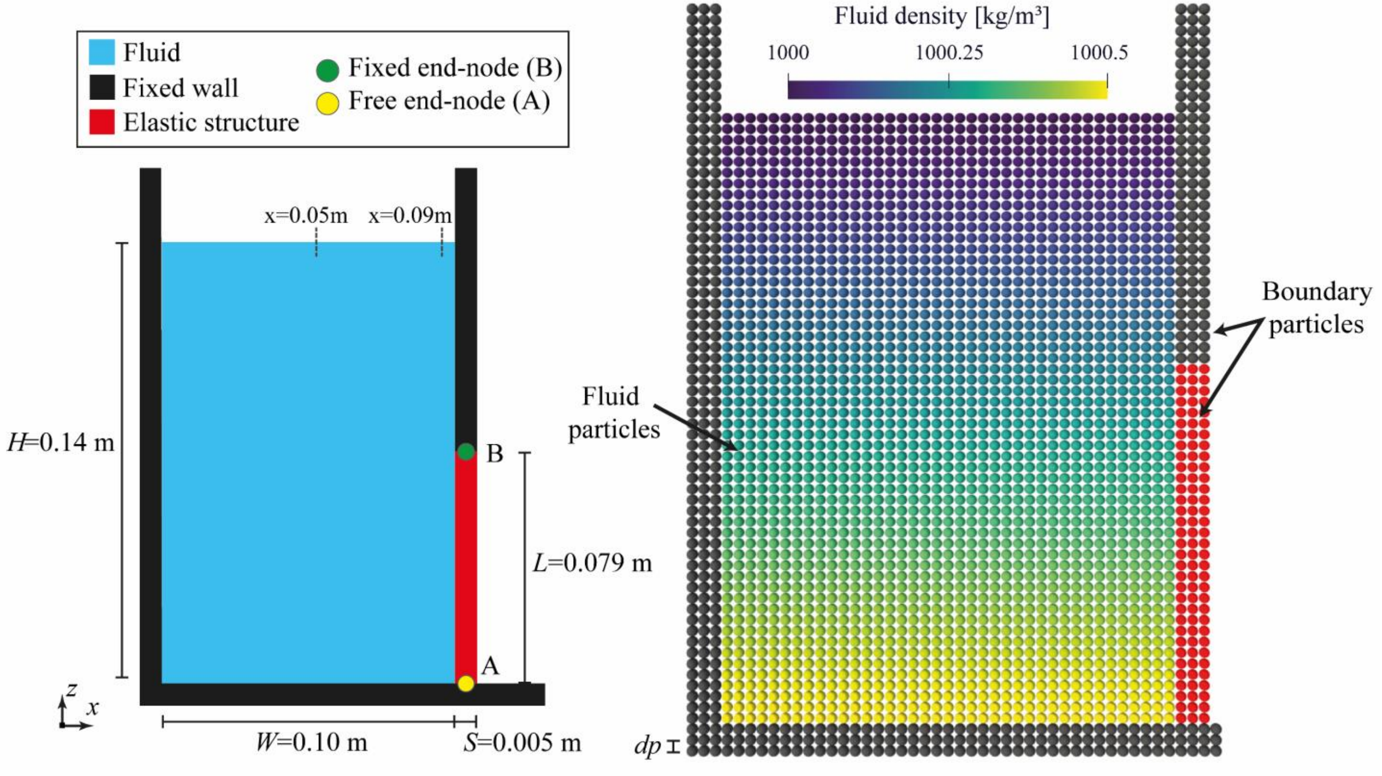
Breaking water-column with an elastic gate

Experimental data from **Antoci et al. (2007)**.

Structure length L=0.079 m.

Structure thickness S=0.005 m.

Parameter	Value
Young's modulus (E)	10 MPa
Poisson's ratio (v)	0.5
Density (ρ)	1100 kg/m^3



GEOMETRIC CONFIGURATION
PARTICLE ARRANGEMENT

Antoci et al. (2007). Numerical simulation of fluid–structure interaction by SPH. *Computers & Structures*, *85*(11), 879–890. https://doi.org/10.1016/j.compstruc.2007.01.002

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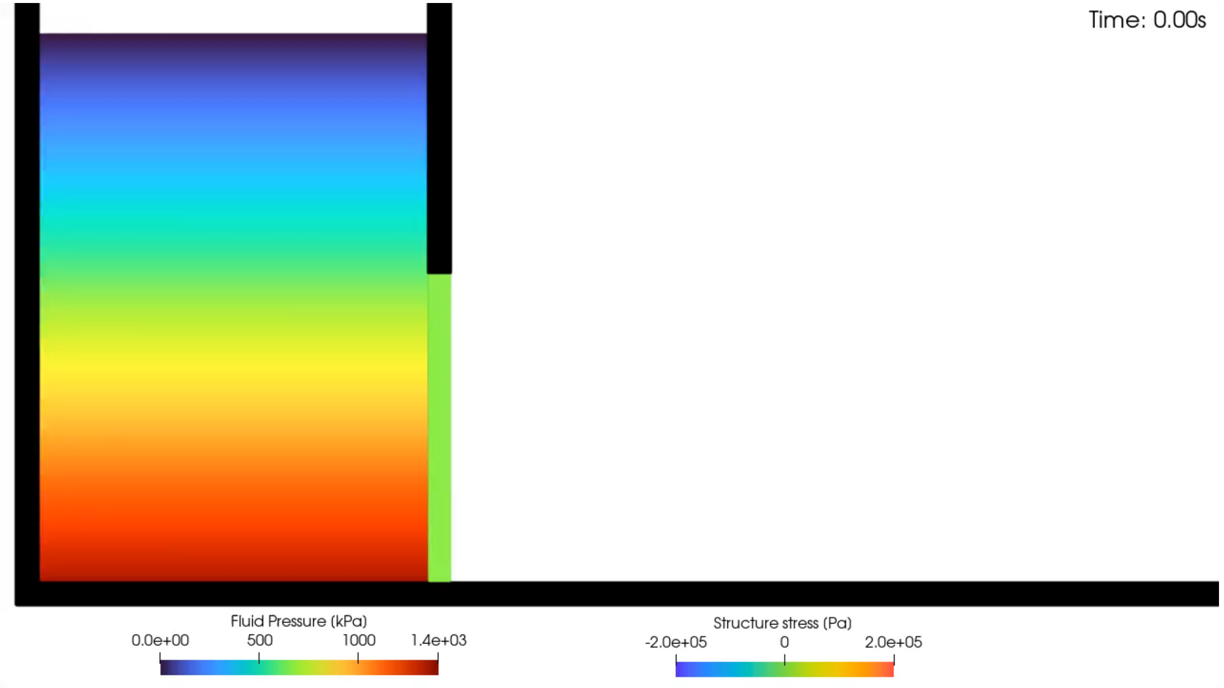
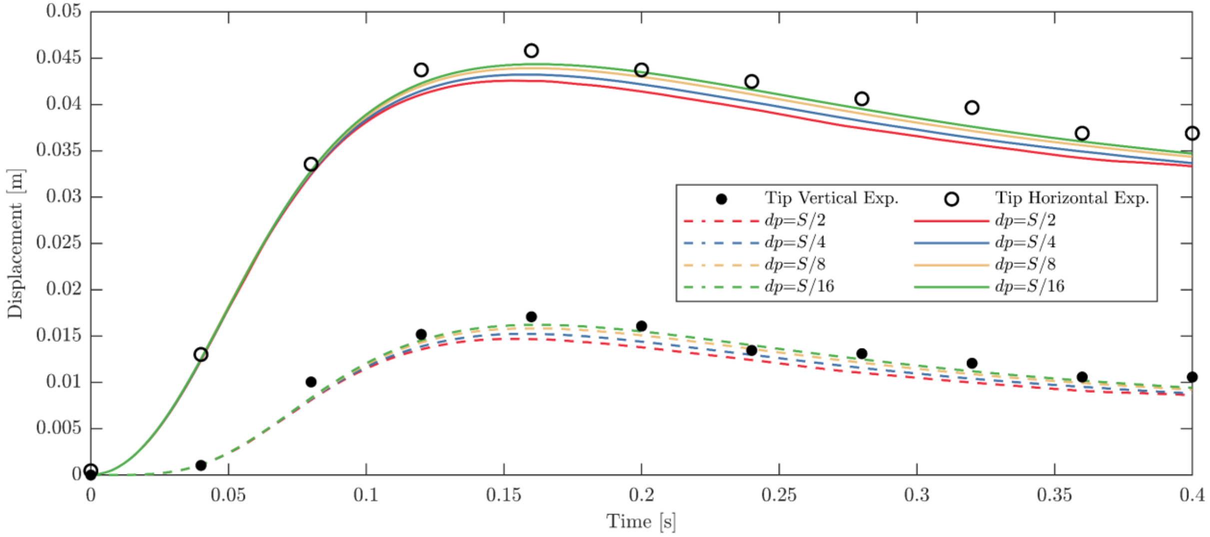
Breaking water-column with an elastic gate

FEA resolution *N*=32 nodes.

SPH resolutions *dp*=*S*/2, *S*/4, *S*/8, *S*/16.



Vertical and horizontal displacement of the structure tip



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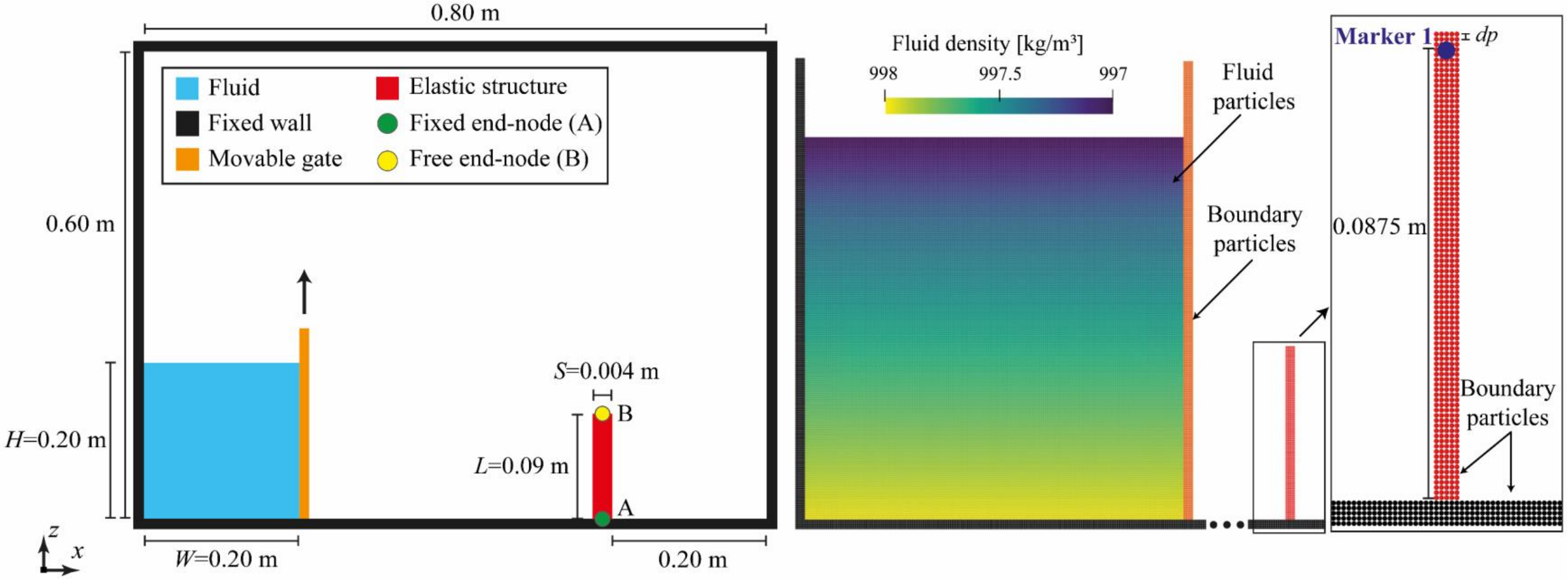
Dam break impacting a flexible obstacle

Experimental data from **Liao et al. (2015)**.

Structure length L=0.09 m.

Structure thickness S=0.004 m.

Parameter	Value
Young's modulus (E)	3.5 MPa
Poisson's ratio (v)	0.5
Density (ρ)	1114 kg/m^3



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Liao et al. (2015). Free surface flow impacting on an elastic structure: Experiment versus numerical simulation. *Applied Ocean Research*, *50*, 192–208. https://doi.org/10.1016/j.apor.2015.02.002

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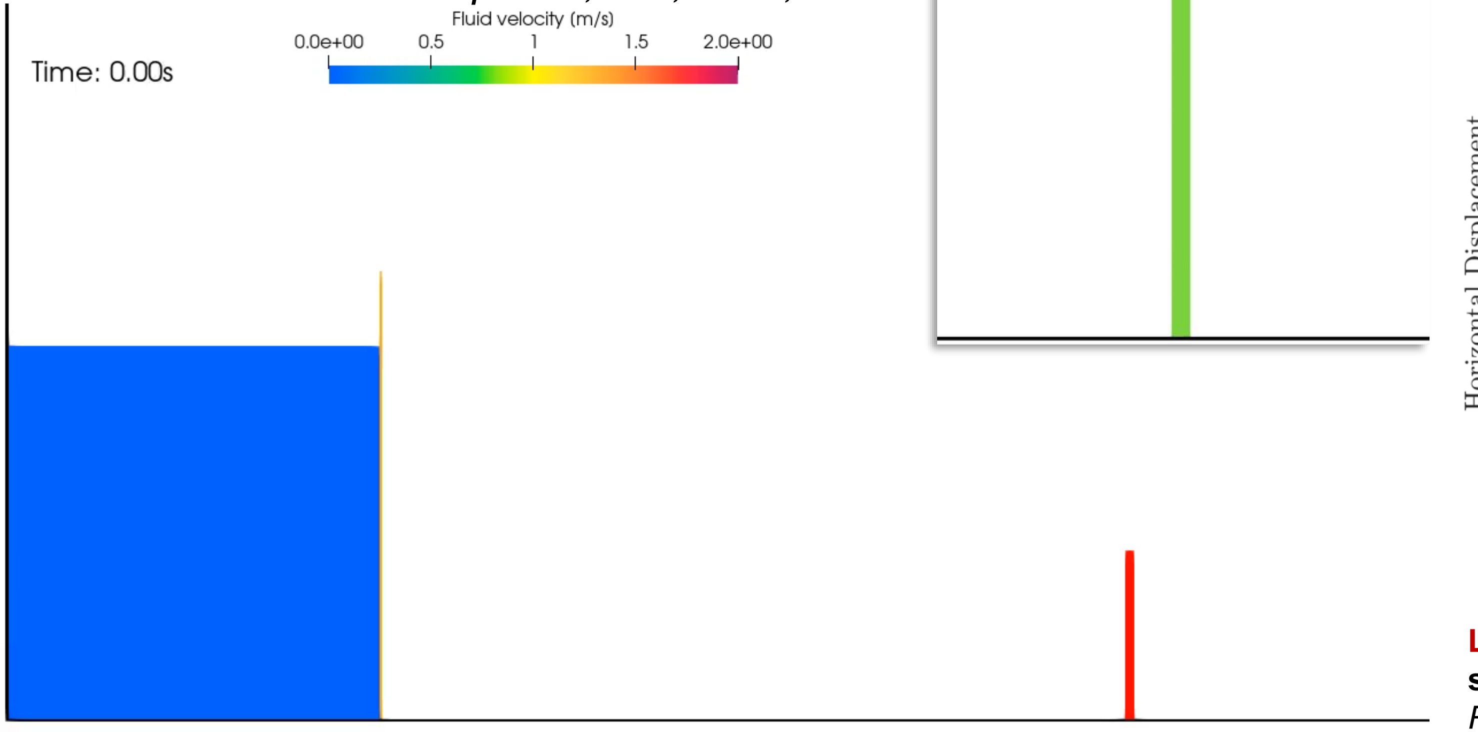
Validation

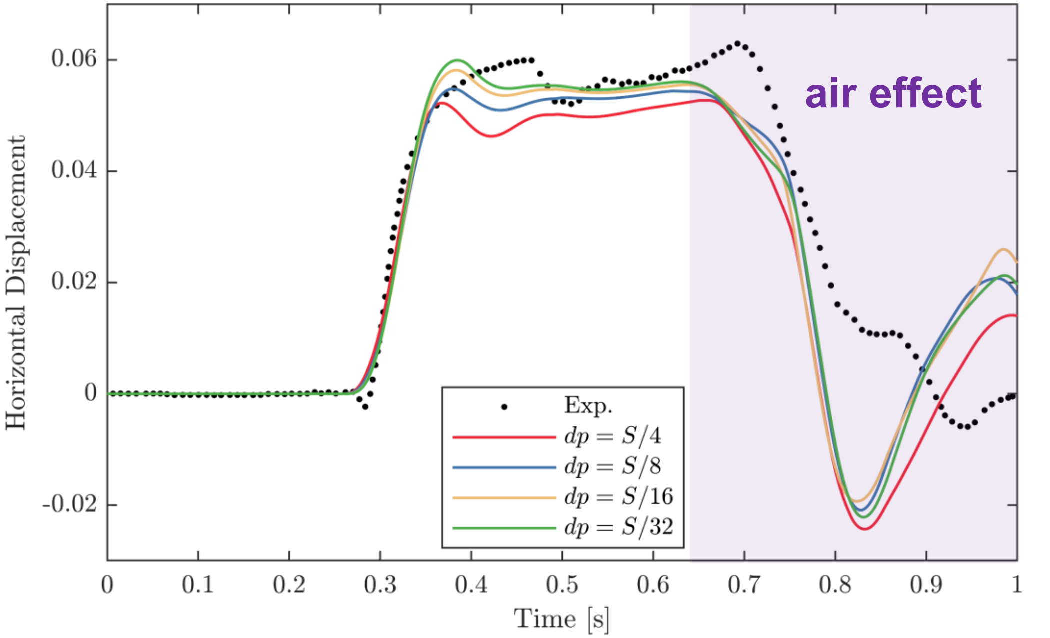
Breaking water-column with an elastic gate

FEA resolution *N*=32 nodes.

SPH resolutions *dp*=*S*/4, *S*/8, *S*/16, *S*/32.



Horizontal displacement histories for the tip of the beam



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XML configuration

FSI in DualSPHysics

Coupling SPH-Chrono

Chrono

1. **Download/clone the forked Chrono's repository**

   https://github.com/imestevez/chrono.git

2. Build the project using CMake

Indicate the path to built cmake (**CMAKE_INSTALL_PREFIX**).

Add Chrono's dependencies (e.g. Eigen library).

Windows: Microsoft Visual Studio 2022 (**Chrono.sln**).

Compiler**:** Microsoft Visual C++ Compiler (MSVC v143).

Linux: *Makefile* will be generated.

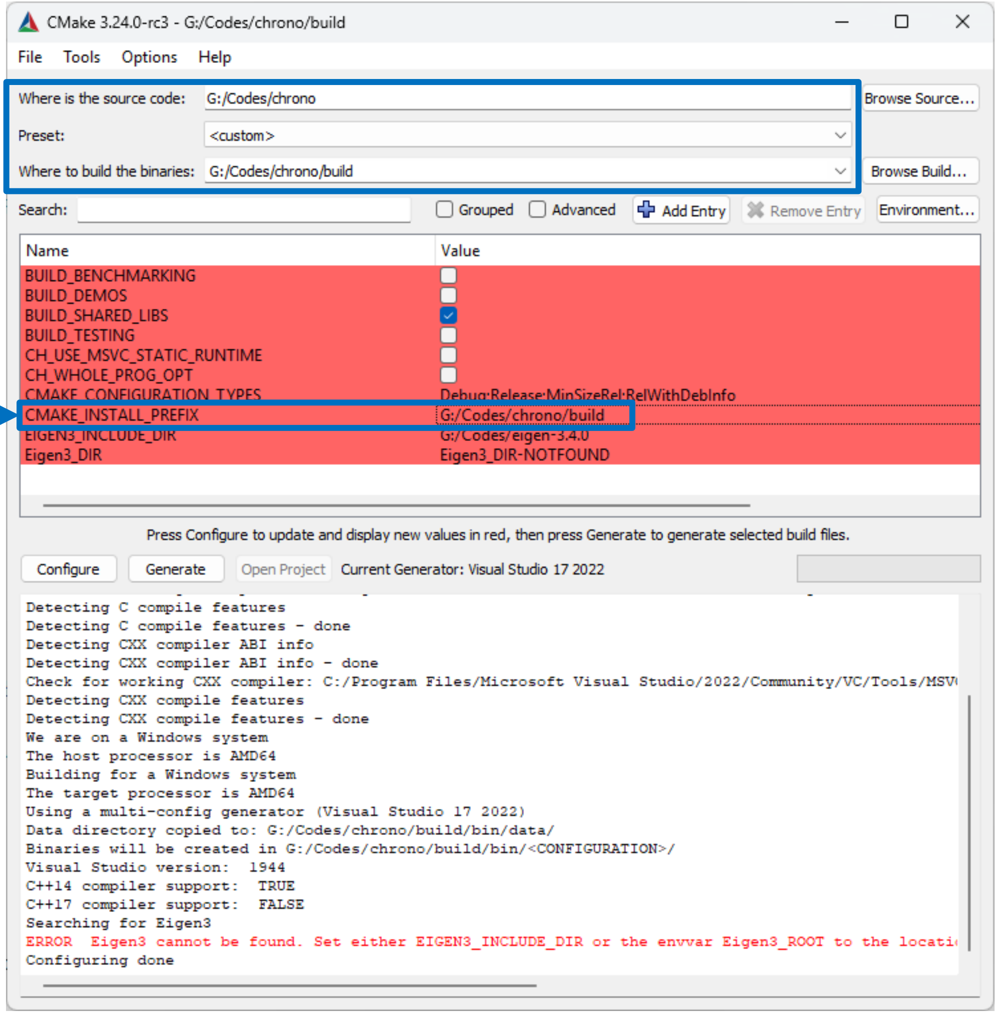
Compiler: g++ >= 11

GNU Make

3. Compile the code in *Release* mode

Windows: Chrono_core.dll

Linux: libChrono_core.so



Coupling SPH-Chrono

DSPHChronoLib

1. **Download/clone the DSPHChronoLib repository**

   https://github.com/DualSPHysics/DSPHChronoLib.git

2. Build the project using CMake

Indicate the cmake folder where Chrono was built (**Chrono_DIR**).

Enable the use of FEA (**ENABLE_FEA=ON**).

Windows: Microsoft Visual Studio 2022 (**DSPHChronoLib.sln**).

Compiler**:** Microsoft Visual C++ Compiler (MSVC v143).

Linux: *Makefile* will be generated.

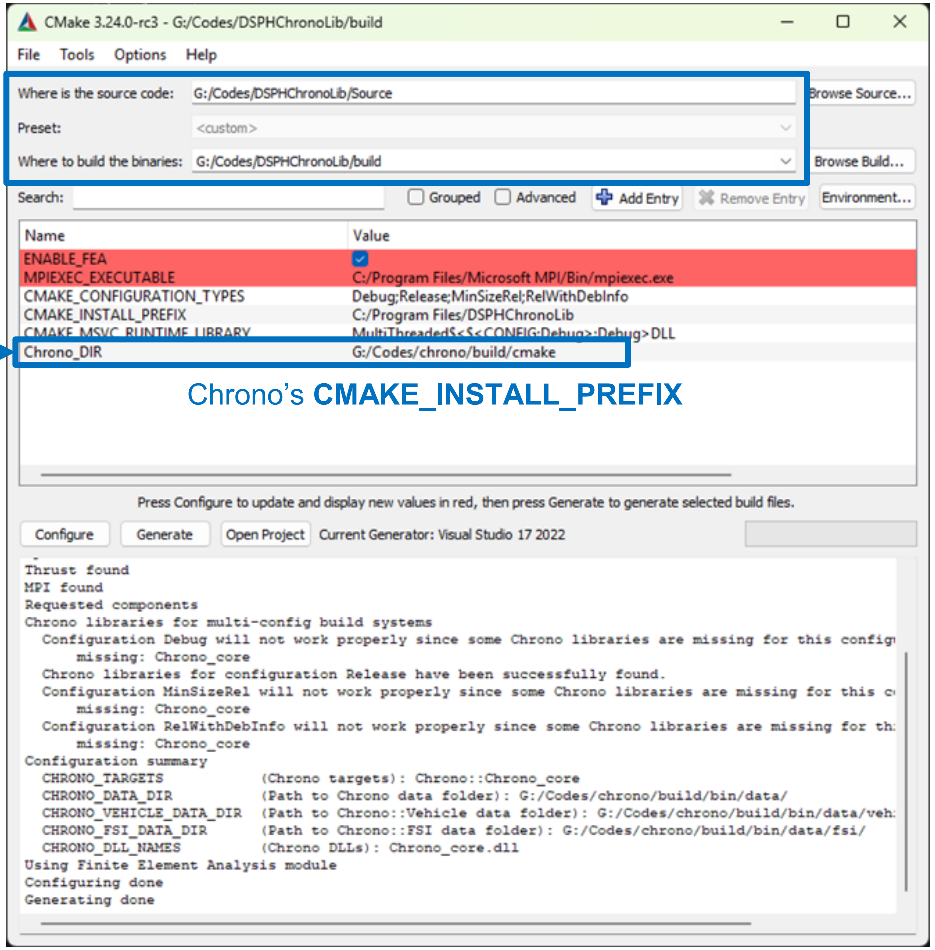
Compiler: g++ >= 11

GNU Make

3. Compile the code in *Release* mode

Windows: dsphchrono.dll/.lib

Linux: libdspchrono.so



Coupling SPH-Chrono

DualSPHysics

binaries
header files
directories

1. Copy/paste resources to the DualSPHysics package.

Header files from DSPHChronoLib/Source **into** DualSPHysics/src/source

- JChronoData.h
- DSPHChronoLib.h

Windows:

- Chrono_core.dll and dsphchrono.dll into DualSPHysics/bin/windows
- dsphchrono.lib into DualSPHysics/src/lib/vs2022

Linux: libChrono_core.so **and** libdsphchrono.so **into both:**

- DualSPHysics/bin/linux
- DualSPHysics/src/lib/linux_gcc

2. Compile the code in *Release|ReleaseCPU* mode

Windows: DualSPHysics_v6.0_win64.exe or DualSPHysics_v6.0CPU_win64.exe

Linux: DualSPHysics_v6.0_linux64 or DualSPHysics_v6.0CPU_linux64

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XML configuration

FSI in DualSPHysics

XML configuration

XML file:
case-execution-special-chrono

savedata: Saves CSV with data exchange

ChronoBody_forces.csv,

ChronoExchange_mkbound_XX.csv

schemescale: Creates VTK file with the initial scheme of Chrono objects using the given scale

CfgChrono_Scheme.vtk

collision: Section to activate collisions

scaleforce: Defines a force scaling factor

bodyfloating & bodyfixed: Indicates the rigid objets to be solved by Chrono

link_*xxxx*: Section to define mechanical constraints.

```xml
<special>
  <chrono>
    <savedata value="0.01" />
    <schemescale value="1" />
    <collision activate="true" />
    <scaleforce>
      <body mkbound="1" x="0.01" y="1" z="1" />
      <body mkbound="2" comment="Scale forces in all directions.">
        <scale time="0" x="0.01" y="1" z="1"/>
        <scale time="10" x="1" y="1" z="0.5"/>
      </body>
    </scaleforce>
    <bodyfixed id="domain" mkbound="0" />
    <bodyfloating id="box1" mkbound="1" />
    <bodyfloating id="box2" mkbound="2" modelfile="box.obj" />
    <link_linearspring idbody1="domain" idbody2="box1" />
    <link_coulombdamping idbody1="domain" idbody2="box1" />
    <link_hinge idbody1="box1" idbody2="box2" />
    <link_spheric idbody1="box2" idbody2="box3" />
    <link_pointline idbody1="box4" />
    <link_pointline idbody1="box4" idbody2="box5" >
    <link_spheric idbody1="box5" />
    <link_pulley idbody1="box1" idbody2="box5" />
  </chrono>
</special>
```

XML configuration

XML file: *case-execution-special-chrono-chronofea* for FEA

```xml
<chrono>
  <configfea>
    <savedata value="0.01" />
    <savevtk value="true" />
    <floating mkbound="1"/>
    <floating mkbound="2">
      <loadforces onlyfile="false" file="ExternalForces.csv"/>
    </floating>
  </configfea>
  ...
</chrono>
```

`configfea`: Section for FEA configuration

`savedata`: Saves CSV data for FEA objects

fea_data/

`savevtk`: Saves VTK files for FEA

NodesVtk/

`floating`: Defines a floating body as a FEA object

`loadforces`: Enables the application of external forces on nodes

`onlyfile`: Indicates if only external forces are applied (`true`) or both fluid+external (`false`)

XML configuration

XML file: *case-execution-special-chrono* for FEA

```xml
<chrono>
  <configfea ... />
  <nodes>
    <node ref="0" fixed="false" x="0" y="0" z="0"/>
    <node ref="1" fixed="false" x="0.35" y="0" z="0"/>
  </nodes>
  <feafloating id="cylinder1" mkbound="1">
    <beamEuler segments="10" >
      <pointA noderef="0" />
      <pointB noderef="1" />
      <section shape="0">
        <radius value="0.04" />
        <density value="7850" />
        <poisson value="0.3" />
        <youngmodulus value="210e6" />
        <rgdamping value="0.0" />
      </section>
    </beamEuler>
  </feafloating>
</chrono>
```

or

```xml
<section shape="1">
  <width value="0.04" />
  <thickness value="0.04" />
```

nodes: Section to define FEA nodes

node: Define the node initial position and if it is fixed or free

feafloating: Define the structure and link it to a floating body using mkbound

beamEuler: Define a Euler-Bernoulli beam

- segments: Number to segments to discretise the beam

pointA & pointB: Indicate the node that are used as start and end points of the beam

section: Properties of the beam and shape

- 0:circular: uses radius
- 1:rectangular: uses width and thickness

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Compiling DualSPHysics-Chrono

XML configuration

FSI in DualSPHysics

FSI in DualSPHysics

	Unified TL-SPH (O'Connor & Rogers, 2021)	SPH–FEA Coupling (Martínez-Estévez et al., 2023b)
Approach	Unified SPH framework for fluid + flexible structures	Two-way, partitioned SPH–FEA coupling
Structural model	Total Lagrangian SPH (TL-SPH) Fully meshless	SPH fluid + FEA mesh-based Euler–Bernoulli beam theory for structure
Numerical coupling	Directly integrated into DualSPHysics framework	DualSPHysics + DSPHChronoLib + Chrono
Computational model	Fully GPU-accelerated both fluid and structure	GPU for fluid and multi-CPU for structure
Structure performance	Computationally demanding due to TL-SPH solid dynamics	Low computational cost due to reduced-order dedicated structural model Requires data exchange between solvers
Use cases / features	Unified, fully meshless flexible FSI within DualSPHysics Valid for any continuum (any geometry) Has simplified constraints (clamped only)	Large deformations and structural dynamics for (slender) structures Handle more complex constraints (e.g. pinned) Extensible to multiphysics: collision detection and multibody dynamics via Chrono

FSI in DualSPHysics

Key message

Unified TL-SPH

A unified, fully meshless SPH formulation in which both the fluid and the flexible structure are solved within DualSPHysics, with the structure represented using a Total Lagrangian SPH (TL-SPH) formulation.

SPH–FEA coupling

A modular DualSPHysics–Chrono framework that couples SPH-FEA for FSI, extensible to multiphysics, with contact/collision handling, multibody dynamics, and alternative structural models.

Important Note

The SPH-FEA approach does not replace the unified TL-SPH formulation; it is a complementary modelling strategy that extends DualSPHysics toward multibody and collision-driven multiphysics FSI.

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Integrating DualSPHysics and Chrono with DSPHChronoLib

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