# MPMICE: A hybrid MPM-CFD model for simulating coupled problems in porous media. Application to earthquake-induced submarine landslides

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## Abstract

In this paper, we describe a soil-fluid-structure interaction model that combines soil mechanics (saturated sediments), fluid mechanics (seawater or air), and solid mechanics (structures). The formulation combines the Material Point Method, which models large deformation of the porous media and the structure, with the Implicit Continuous-fluid Eulerian, which models complex fluid flows. We validate the model and simulate the whole process of earthquake-induced submarine landslides. We show that this model captures complex interactions between saturated sediment, seawater, and structure, so we can use the model to estimate the impact of potential submarine landslides on offshore structures.

*Keywords:*
Material Point Method, MPMICE, submarine landslide.

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## Nomenclature

### General variables

| Variable | Dimensions | Description |
|---|---|---|
| $V$ | $[L^3]$ | Representative volume |
| $n$ | | Porosity |
| $\boldsymbol{\sigma}$ | $[ML^{-1}t^{-2}]$ | Total stress tensor |
| $\Delta t$ | $[t]$ | Time increment |
| $\boldsymbol{b}$ | $[ML^1t^{-2}]$ | Body force |
| $c_v$ | $[L^2t^{-2}T^{-1}]$ | Constant volume specific heat |
| $f_d$ | $[MLt^{-2}]$ | Drag forces in momentum exchange term |
| $f^{int}$ | $[MLt^{-2}]$ | Internal forces |
| $f^{ext}$ | $[MLt^{-2}]$ | External forces |
| $q_{fs}$ | $[MLt^{-2}]$ | Heat exchange term |
| $S$ | | Weighting function |
| $\nabla S$ | | Gradient of weighting function |

### Solid phase

| Variable | Dimensions | Description |
|---|---|---|
| $m_s$ | $[M]$ | Solid mass |
| $\rho_s$ | $[ML^{-3}]$ | Solid density |
| $\phi_s$ | | Solid volume fraction |
| $\overline{\rho}_s$ | $[ML^{-3}]$ | Bulk Solid density |
| $\boldsymbol{x}_s$ | $[L]$ | Solid Position vector |
| $\boldsymbol{U}_s$ | $[Lt^{-1}]$ | Solid Velocity vector |
| $\boldsymbol{a}_s$ | $[Lt^{-2}]$ | Solid Acceleration vector |
| $\boldsymbol{\sigma}'$ | $[ML^{-1}t^{-2}]$ | Effective Stress tensor |
| $\boldsymbol{\epsilon}$ | | Strain tensor |
| $e_s$ | $[L^2t^{-2}]$ | Solid Internal energy per unit mass |
| $T_s$ | $[T]$ | Solid Temperature |
| $\boldsymbol{F}_s$ | | Solid Deformation gradient |
| $V_s$ | $[L^3]$ | Solid Volume |

**Fluid phase**

| Variable | Dimensions | Description |
|---|---|---|
| $m_f$ | $[M]$ | Fluid mass |
| $\rho_f$ | $[ML^{-3}]$ | Fluid density |
| $\phi_f$ | | Fluid volume fraction |
| $\overline{\rho}_f$ | $[ML^{-3}]$ | Bulk Fluid density |
| $\boldsymbol{U}_f$ | $[Lt^{-1}]$ | Fluid Velocity vector |
| $\boldsymbol{\sigma}_f$ | $[ML^{-1}t^{-2}]$ | Fluid stress tensor |
| $p_f$ | $[ML^{-1}t^{-2}]$ | Fluid isotropic pressure |
| $\boldsymbol{\tau}_f$ | $[ML^{-1}t^{-2}]$ | Fluid shear stress tensor |
| $e_f$ | $[L^2t^{-2}]$ | Fluid Internal energy per unit mass |
| $T_f$ | $[T]$ | Fluid Temperature |
| $\upsilon_f$ | $[L^3/M]$ | Fluid Specific volume $\frac{1}{\rho_f}$ |
| $\alpha_f$ | $[1/T]$ | Thermal expansion |
| $\mu$ | $[ML^{-1}t^{-1}]$ | Fluid vicousity |
| $V_f$ | $[L^3]$ | Fluid Volume |

**Superscript**

| Variable | Dimensions | Description |
|---|---|---|
| $n$ | | Current time step |
| $L$ | | Lagrangian values |
| $n+1$ | | Next time step |

**Subscript**

| | | |
|---|---|---|
| $c$ | | Cell-centered quantity |
| $p$ | | Particle quantity |
| $i$ | | Node quantity |
| $FC$ | | Cell face quantity |
| $L, R$ | | Left and Right cell faces |