Graphical Abstract

MPMICE2

Quoc Anh Tran

Highlights

MPMICE2

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- Research highlight 1
- Research highlight 2

MPMICE2

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[a], , , , ,

Abstract

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Keywords:

Contents

Nomenclature

General variables

Variable	Dimensions	Description
V	$[L^3]$	Representative volume
n		Porosity
$\boldsymbol{\sigma}$	$[M/L^2]$	Total stress tensor
Δt	$[t]$	Time increment
$\boldsymbol{b}$	$[L/t]$	Gravity acceleration
c_v	$[L^2/t^2]$	Constant volume specific heat
f_{fs}	$[ML//t^2]$	Drag forces in momentum exchange term
f^{int}	$[ML//t^2]$	Internal forces
f^{ext}	$[ML//t^2]$	External forces
q_{fs}	$[ML//t^2]$	Heat exchange term
S		Shape function
∇S		Gradient of shape function

Solid phase

Variable	Dimensions	Description
m_s	$[M]$	Solid mass
ρ_s	$[M/L^3]$	Solid density
ϕ_s	$-]$	Solid volume fraction
$\overline{\rho}_s$	$[M/L^3]$	Average Solid density
$\boldsymbol{x}_s$	$[L]$	Solid Position vector
$\boldsymbol{U}_s$	$[L/t]$	Solid Velocity vector
$\boldsymbol{U}_s$	$[L/t]$	Solid Velocity gradient vector
$\boldsymbol{a}_s$	$[L/t^2]$	Solid Acceleration vector
$\boldsymbol{\sigma}'$	$[M/L^2]$	Effective Stress tensor
e_s	$[L^2/t^2]$	Solid Internal energy
T_s	$[T]$	Solid Temperature
$\boldsymbol{F}_s$		Solid Deformation gradient
V_s	$[L^3]$	Volume

Fluid phase

Variable	Dimensions	Description
m_f	$[M]$	Fluid mass
ρ_f	$[M/L^3]$	Fluid density
ϕ_f	$-]$	Fluid volume fraction
$\overline{\rho}_f$	$[M/L^3]$	Average Fluid density
$\boldsymbol{U}_f$	$[L/t]$	Fluid Velocity vector
$\boldsymbol{\sigma}_f$	$[M/L^2]$	Fluid stress tensor
Δp_f	$[M/L^2]$	Fluid isotropic pressure
$\boldsymbol{\tau}_f$	$[M/L^2]$	Fluid shear stress tensor
p_f	$[M/L^2]$	Isotropic pressure
e_f	$[L^2/t^2]$	Fluid Internal energy $(c_v T_f)$ of the material per unit mass
T_f	$[T]$	Fluid Temperature
υ_f	$[L^3/M]$	Fluid Specific volume $\frac{1}{\rho_f}$
α_f	$[1/T]$	Thermal expansion
μ	$[M/L^2T]$	Fluid vicousity

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		Face-centered quantity
L, R		Left and Right cell faces

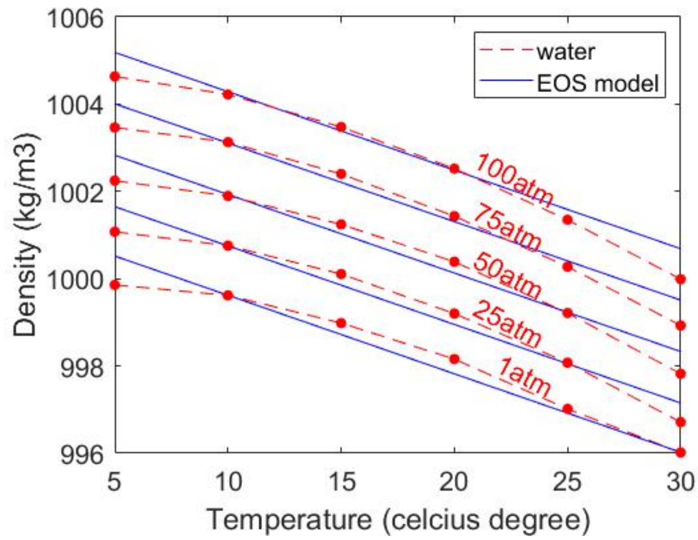


Figure 1: Equation of state of water

Introduction

write introduction

Theory and formulation

Assumptions

Governing equations

Balance equations

Equation of state for fluid plases

Constitutive soil model

Momentum and Energy exchange model

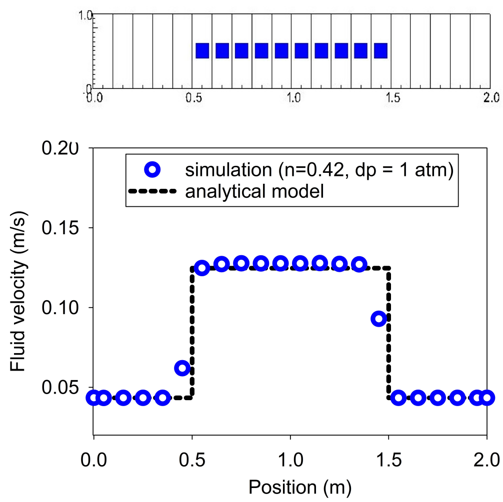
Turbulent model

Numerical implementation

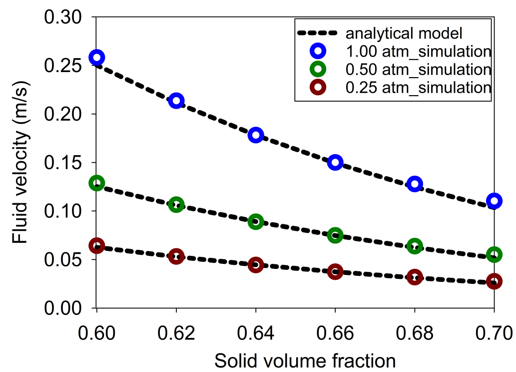
Numerical examples

All input files and the analytical calculations in this section are provided in the Github repository [1] for the reproduction of the numerical results.

[1]https://github.com/QuocAnh90/Uintah NTNU



(a)



(b)

Figure 2: (a) Discretization of the model and (b) comparision between analytical model and simulation

Fluid Flow through isothermal porous media

Fluid flow through porous media is important in many engineering disciplines, like predicting water flow in soil. Fluid flow velocity in one dimension can be calculated from the porous media's hydraulic conductivity K as:

$$U_f = K\frac{\Delta p_f}{L} \tag{1}$$

If the Carman-Kozeny formula is adopted $F = 10p/(1-p)^4$, the hydraulic conductivity will be expressed as $K = d^2(1-\phi_s)^3/180\mu\phi_s^2$. Then, the analytical formula of average velocity in one dimension through the porous media is::

$$U_f = \frac{1}{n}\frac{d^2(1-\phi_s)^3}{180\mu\phi_s^2}\frac{\Delta p_f}{L} \tag{2}$$

Our numerical model is validated by modeling fluid flow through a 1m long porous media. This fluid has water properties (bulk modulus is 2GPa, density is 998 kg/m3 at 5 degrees Celsius and 10325 Pa (1atm) pressure, dynamic viscosity μ is 1mPa s). The porous media is modeled by elastic material with Young's modulus is 10 MPa, Poisson's ratio is 0.3, and density is 2650

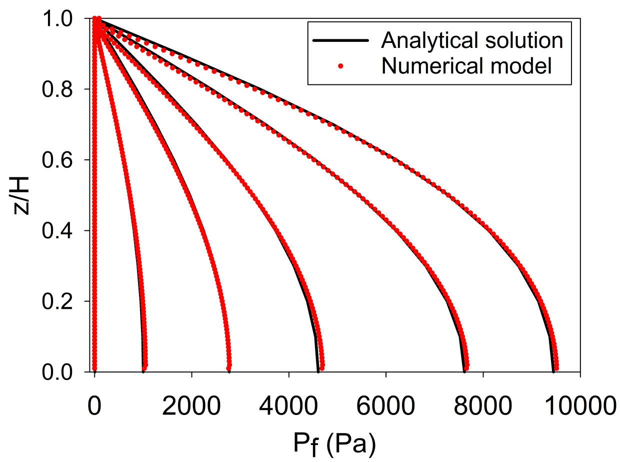


Figure 3: Compasion between analytical solution and numerical solution

kg/m3. The volume fraction of porous media ϕ_s is [0.6, 0.62, 0.66, 0.68, 0.7] and the average grain diameter d is 1mm. The model is discretized in 20 finite element and the porous media in 10 finite element with 1 material point per element. The pressure gradient is applied with three different value [0.25, 0.5, 1] atm. Figure 2 shows the comparision of fluid flow prediction between the theory and the model.

Isothermal consolidation

A common benchmark fo a fully saturated porous meida is the simulation of one-dimensional consolidation. Using the Carman-Kozeny formula, the time-dependent pressure can be caluated as:

$$p_f = \sum_{m=1}^{\infty} \frac{2F_{ext}}{M} \sin(\frac{Mz}{H}) e^{-M^2 T_V} \text{ with } M = \frac{\pi}{2}(2m+1) \tag{3}$$

where the consolidation rate $T_v = C_v t/H^2$, the consolidation coefficient $C_v = E_v n^3 d^2/(180(1-n)^2\mu)$ and the Oedometer modulus $E_v = E(1-v)/(1+v)/(1-2v)$.

Our numerical model is validated by modeling the consolidation of a 1m column. This fluid has water properties (bulk modulus is 2GPa, density is 998 kg/m3 at 5 degrees Celsius and 10325 Pa (1atm) pressure, dynamic

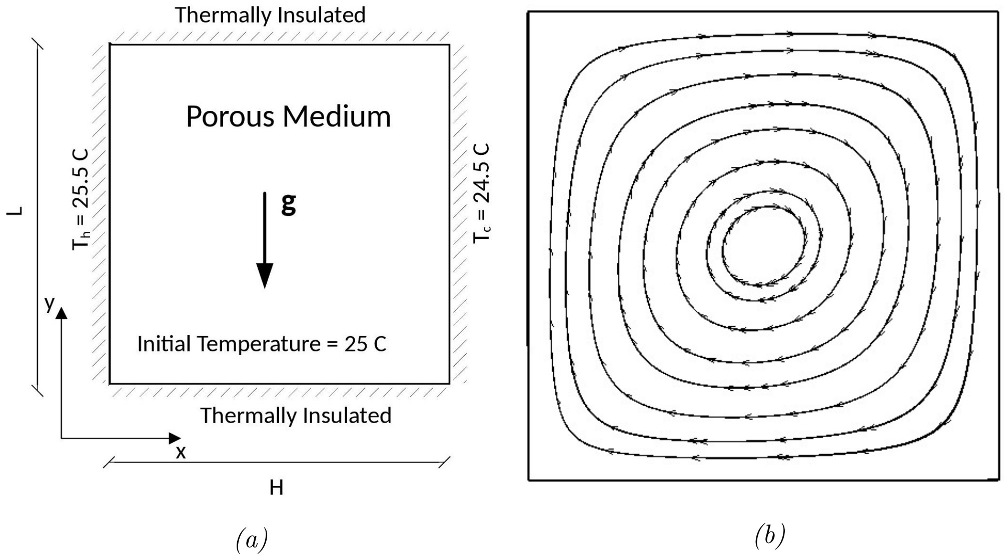


Figure 4: (a) Discretization of the model and (b) comparision between analytical model and simulation

viscosity μ is 1mPa s). The porous media is modeled by elastic material with Young's modulus is 10 MPa, Poisson's ratio is 0.3, and density is 2650 kg/m3. The volume fraction of porous media ϕ_s is 0.7 which is equivalent to the porosity of 0.3 and the average grain diameter d is 1mm. The model is discretized in 100 finite element with 1 material point per element. The external pressure applies to the top of the column is 10 kPa. Figure 3 shows the comparision of fluid flow prediction between the theory and the model.

thermal induced cavity flow

Another benchkmark is the thermal induced cavity flow in porous media. Temperature and velocity distributions are calculated for a square non-deformable saturated porous media The top and bottom walls are insulated, and the left and right walls are at fixed temperatures differing by 1 K. The fluid motion at stead state are cavity flow due to the temperature induced density variation.

The numerical is validated by comparing with the numerical solution of the finite element method. The fluid has water properties (bulk modulus is 2GPa, density is 998 kg/m3 at 5 degrees Celsius and 10325 Pa (1atm) pressure, dynamic viscosity μ is 1.5mPa s). The porous media is modeled by non deformable material, and density is 2500 kg/m3. The specific heat capacity of the water and porous skeleton are 4181 J/kg.K and 835 J/kg.K respectively. The thermal conductivity of the water and porous skeleton are x and x. The volume fraction of porous media ϕ_s is 0.6 which is equivalent to the porosity of 0.4 and the average grain diameter d is 1mm. The model is discretized in x finite element with x material point per element. Figure **??** shows the numerical results of the model compared with the numerical solution of the finite element method.

debris flow

granular column collapse

earthquake-induced submarine landslides

Conclusions

Appendix

References

[1]