



Technische
Universität
Braunschweig



Leichtweiß-Institute for Hydraulic Engineering and Water Resources
Department of Hydromechanics and Coastal Engineering



CFD-CSD Model System For Foundations Of Marine Gravity Structures

Hisham El Safti and Hocine Oumeraci | 26.2.2013 | FZK Kolloquium, Feb. 2013,
Coastal Research Center (FZK) Hanover

Outline

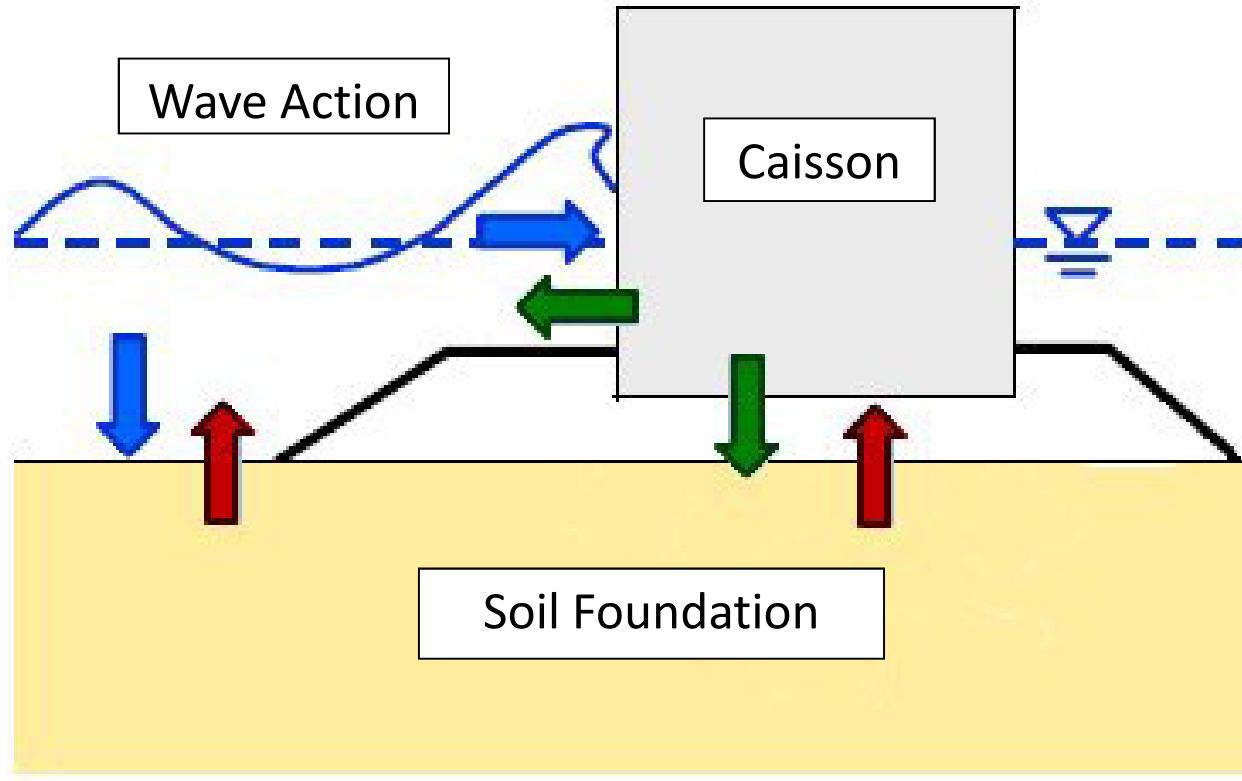
- Motivation
- Hydrodynamic (CFD) model (*waveVolAvgPorousInterFoam*)
- Linking both models
- Hydro-geotechnical (CSD) Model (*geotechFoam*)
- Concluding remarks and outlook



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Wave-Structure-Foundation Interaction



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Hydrodynamic Model

- Modifying *porousInterFoam* with *waves2Foam* toolbox
- Volume averaging of porous media
- Additional term for fluid compressibility

$$\nabla \cdot \bar{\mathbf{U}} + \frac{1}{Q} \frac{\partial p}{\partial t} = 0$$

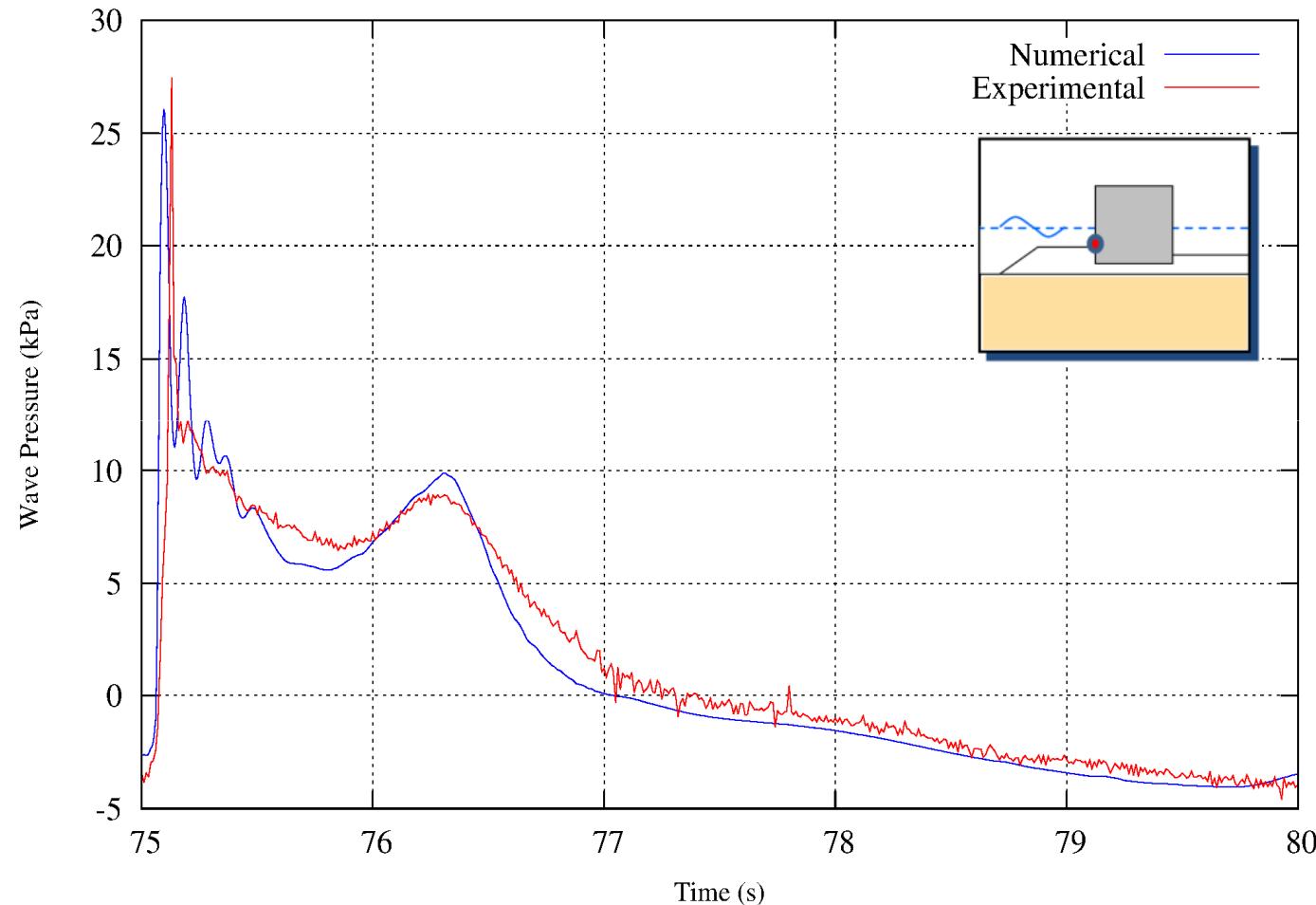
$$\rho_f \left(\frac{(1+c_A)}{n} \frac{\partial \bar{\mathbf{U}}}{\partial t} + \frac{1}{n^2} \bar{\mathbf{U}} \cdot \nabla \bar{\mathbf{U}} \right) = -\nabla p + \frac{1}{n} \left(\nabla \cdot (\boldsymbol{\tau} + \frac{\mathbf{R}}{n}) \right) + \rho_f \mathbf{b} - \mathbf{S}$$

- Several seepage models (e.g. Lin and Karunarathna, 2007)

$$I = -\frac{1}{\rho g} \nabla p = \underbrace{a \bar{\mathbf{U}}}_{\substack{\text{viscous} \\ (\text{laminar})}} + \underbrace{c \bar{\mathbf{U}} \sqrt{|\bar{\mathbf{U}}|}}_{\substack{\text{(transitional)}}} + \underbrace{b \bar{\mathbf{U}} |\bar{\mathbf{U}}|}_{\substack{\text{inertial} \\ (\text{turbulent})}} + \underbrace{\frac{(1+c_A)}{ng} \frac{\partial \bar{\mathbf{U}}}{\partial t}}_{\text{transient}}$$

Breaking Wave Impact

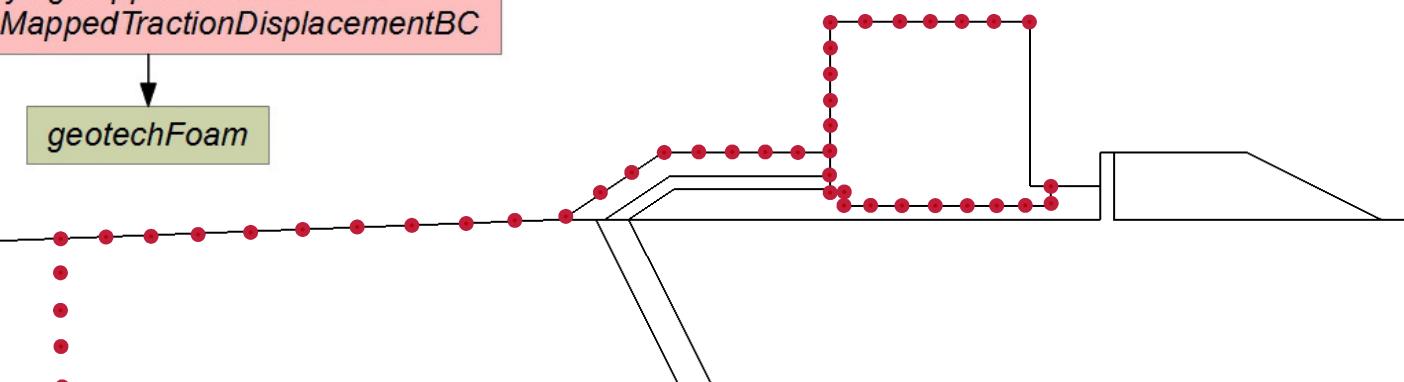
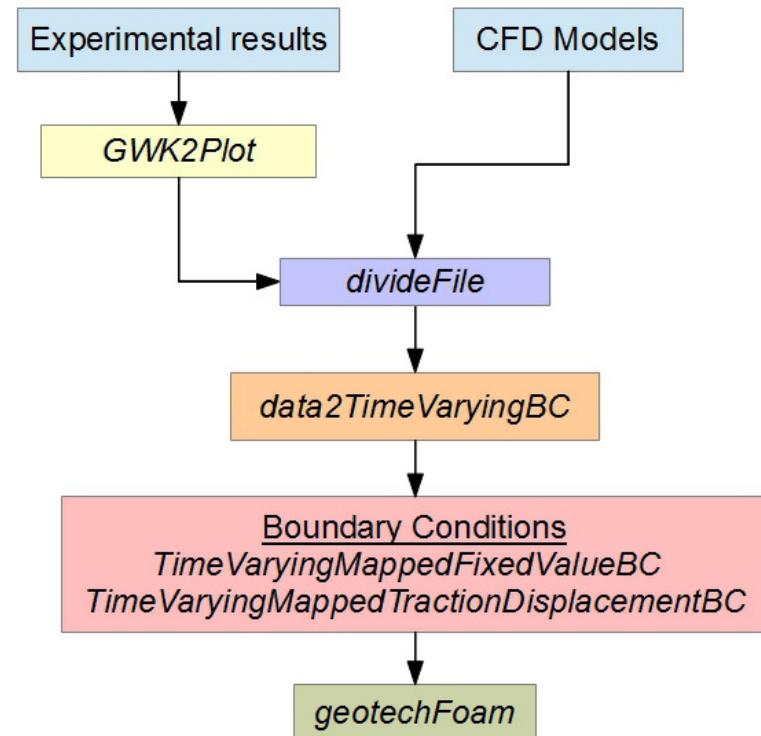
Wave pressure transducer 56 for test 10090203



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Coupling Procedure



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The Governing Equations (Fully Dyn.)

- Mixture momentum balance (*equilibrium equation*)

$$\nabla \cdot \boldsymbol{\sigma} - \rho \frac{\partial^2 \mathbf{u}}{\partial t^2} - \rho_f \left(\frac{\partial \bar{\mathbf{U}}}{\partial t} + \bar{\mathbf{U}} \cdot \nabla \bar{\mathbf{U}} \right) + \rho \mathbf{b} = 0$$

- Pore-fluid *momentum* balance

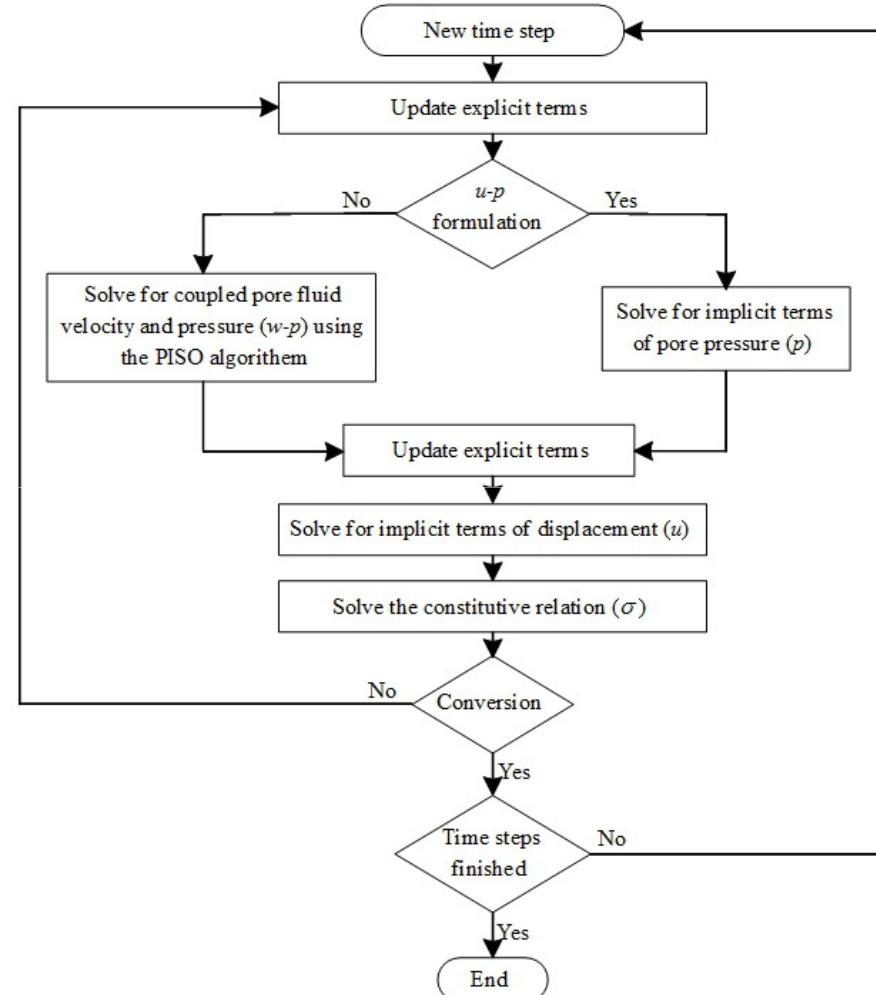
$$\rho_f \left(\frac{\partial \bar{\mathbf{U}}}{\partial t} + \bar{\mathbf{U}} \cdot \nabla \bar{\mathbf{U}} \right) / n = -\nabla p - \mathbf{S} - \rho_f \frac{\partial^2 \mathbf{u}}{\partial t^2} + \rho_f \mathbf{b}$$

- Pore-fluid *mass* balance

$$\nabla \cdot \bar{\mathbf{U}} + \frac{\partial \varepsilon_v}{\partial t} + \frac{1}{Q} \frac{\partial p}{\partial t} = 0$$

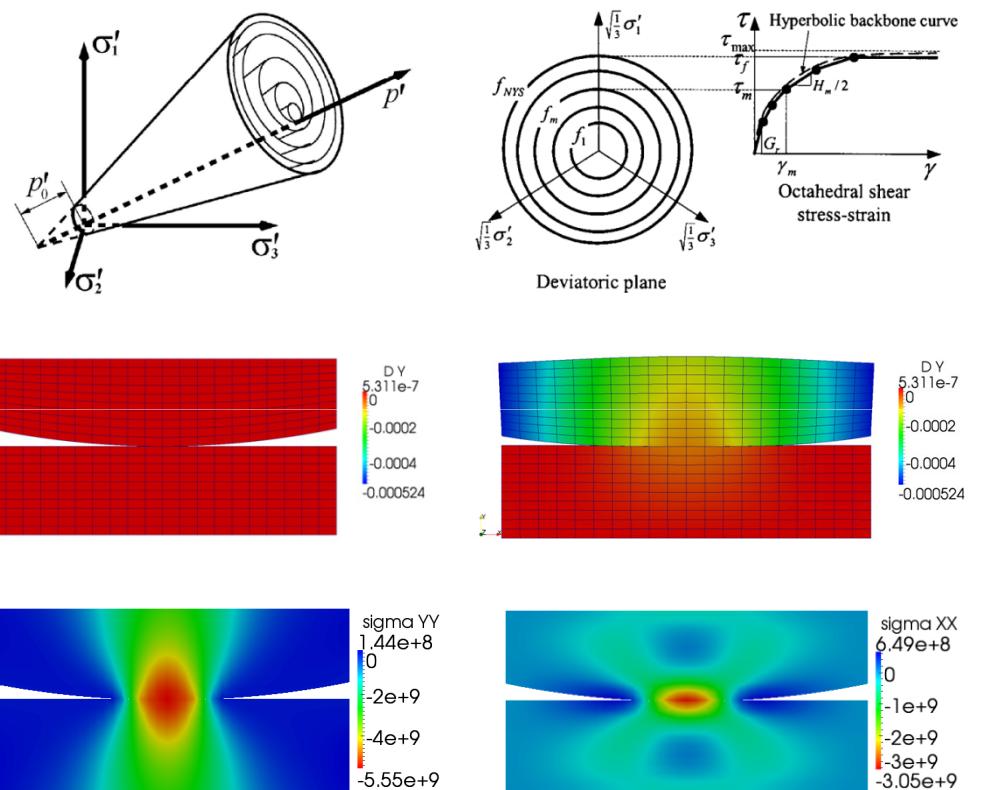
Solver Algorithm

- Segregated algorithm
- Equations discretisation:
 - Implicit terms
 - Explicit terms
- For the fully dynamic formulation:
 - PISO algorithm (from CFD)
 - Fluid momentum balance is solved unlike ($u-p$) approximation

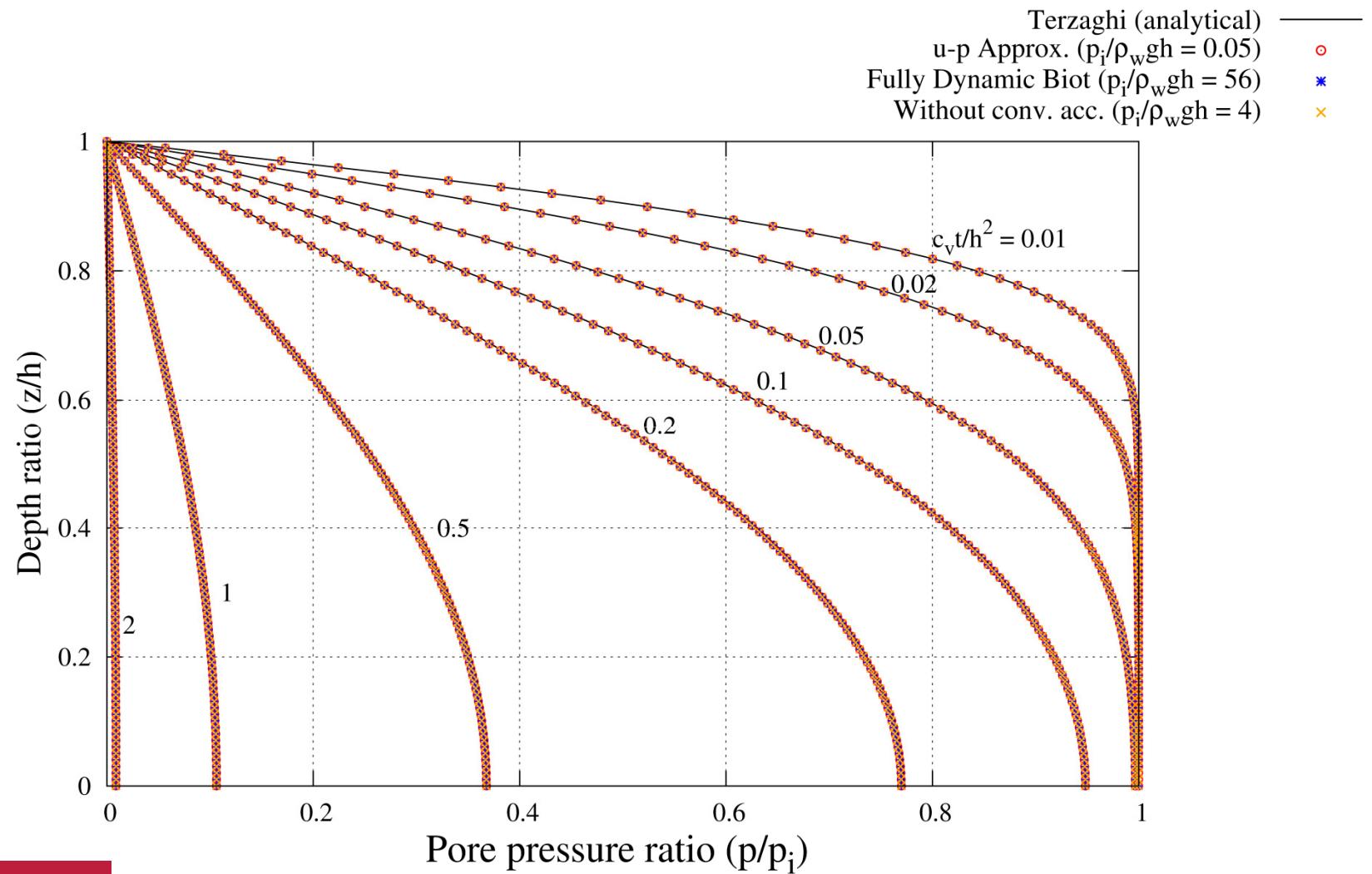


Solver Features

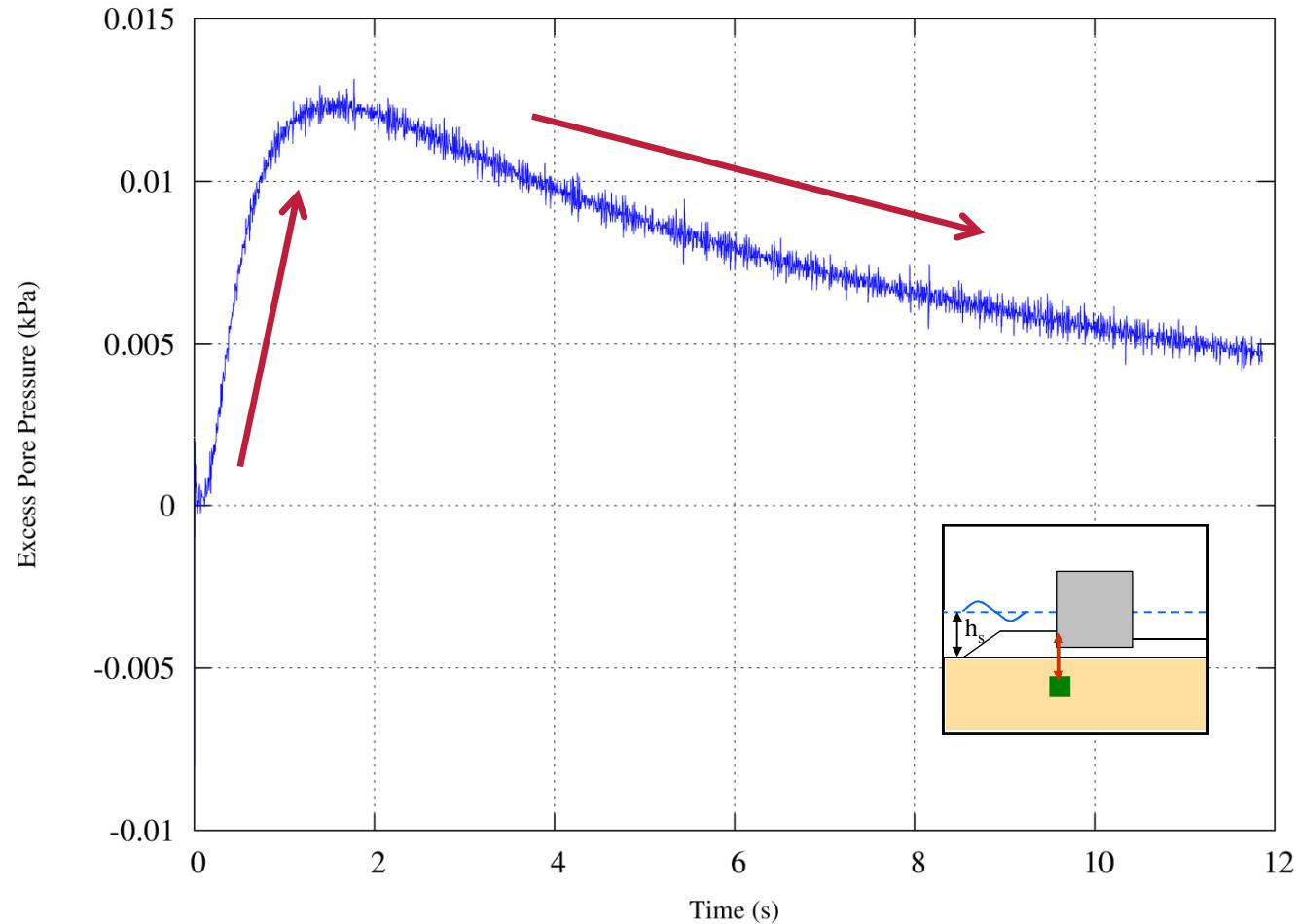
- Displacement (Lagrangian) and pore fluid (Eulerian)
- Different zones of material models in the same domain
- Multi surface plasticity model for modelling sand behaviour under cyclic loading
- Viscoelasticity – Damping
- Frictional contact model



1-D Consolidation



Residual Pore Pressure



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Concluding Remarks

- Using the PISO algorithm for fluid (velocity-pressure) coupling
- Introducing the new **fluid compressibility** term to the fluid continuity equation enhances results for **breaking wave impact**
- The model is very **sensitive** to changes in air content in (pore) fluid (i.e. change in pore **fluid bulk modulus**)
- The ***u-p*** approximation is significantly **faster** than the fully dynamic formulation
- In the **fully dynamic** formulation, the accumulation/dissipation of pore pressure is affected by the **excess to hydrostatic pore pressure ratio**. *The effect is less if convection is neglected and when the fluid bulk modulus increases*
- The formulation allows introduction of different **soil constitutive models**.

Outlook

- Applications of the currently developed model (e.g. caisson breakwaters, gravity foundations of offshore wind farms)
- Introduce two-way coupling: more general and applies to flexible structures
- Introducing strong coupling (same set of governing equations) suitable for highly deformable porous media (e.g. seabed, dikes, vegetation)
- Introducing an Eulerian treatment of the porous media skeleton and hence other processes can be accounted for (e.g. sediment transport)



Thank You for Your Attention

Hisham El Safti
**Leichtweiß-Institute for Hydraulic
Engineering and Water Resources**
TU Braunschweig, Germany
Tel.: +49 531 391 3925
www.tu-braunschweig.de/lwi/hyku/
h.el-safti@tu-braunschweig.de



DAAD