COMSOL CONFERENCE
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Politecnico di Torino

NUMERICAL PREDICTION OF THE EIGENFREQUENCIES OF AN IDEALIZED BRIDGE PIER UNDER LOCAL SCOUR

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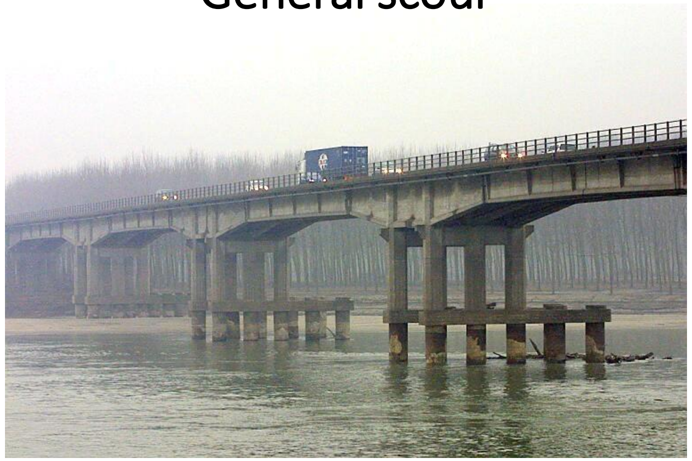
INTRODUCTION AND MOTIVATION

Local scour

General scour



Bridge scour

- Bridge scour is the result of the erosive action of flowing water, which excavates and carries away material from the riverbed

- Scour can cause the subsidence and tilt of the piers, contributing to 60% of failures of road bridges (e.g., *Imhof 2004*)

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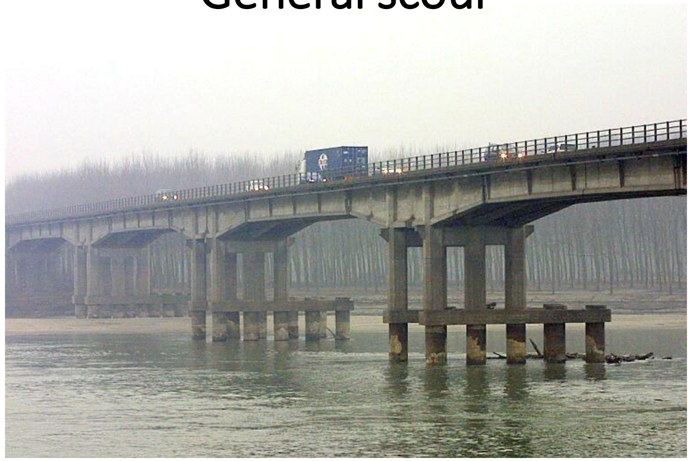

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Collapse of the Chisone bridge (Torino, 2000)

Collapse of the Longobucco bridge, (Cosenza, 2023)

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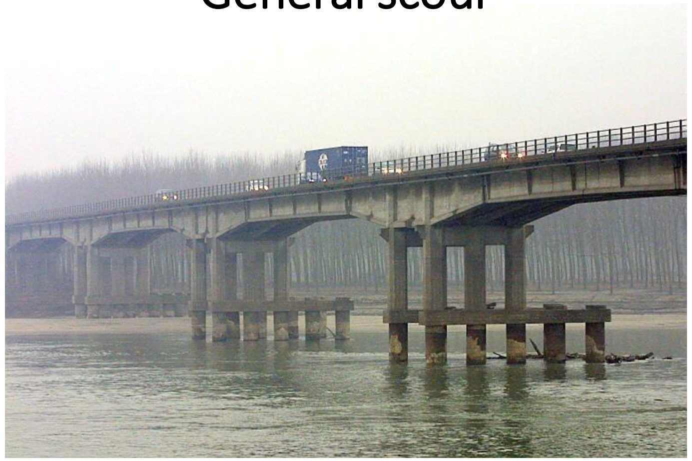

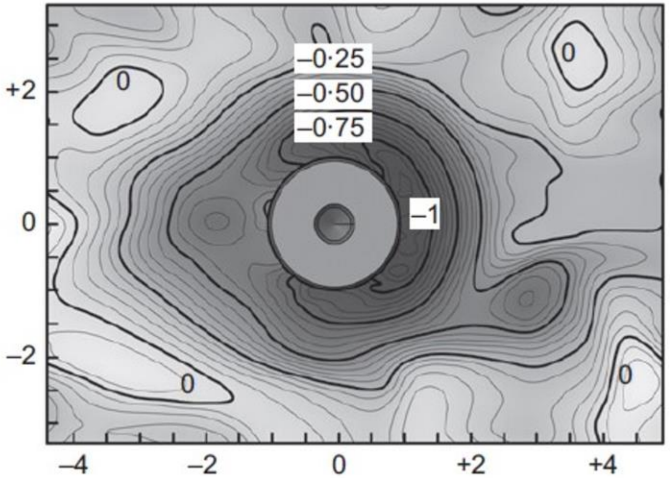

Ciancimino et al. (2022a)

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- Scour can cause the subsidence and tilt of the piers, contributing to 60% of failures of road bridges (e.g., *Imhof 2004*)
- Proper modeling requires rigorous representation of the problem geometry and adequate constitutive models to reproduce the soil response → **Advanced numerical simulations**

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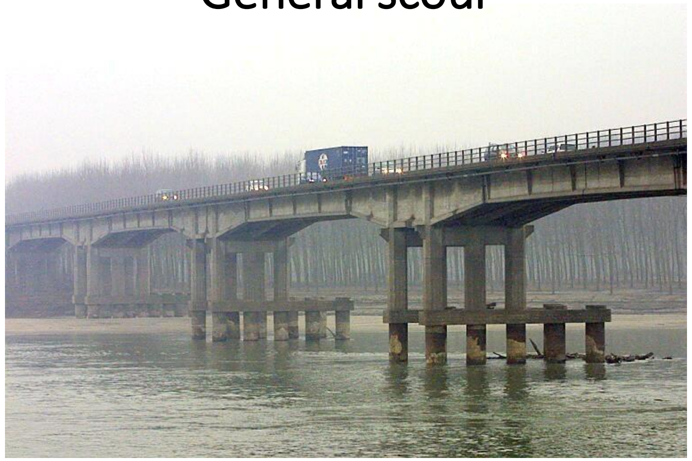

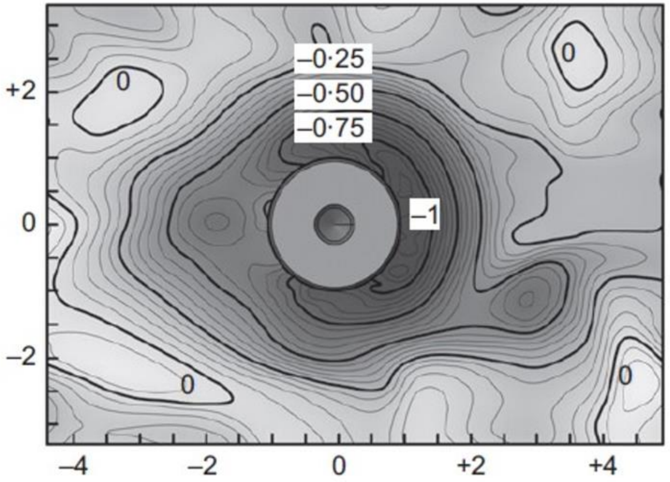

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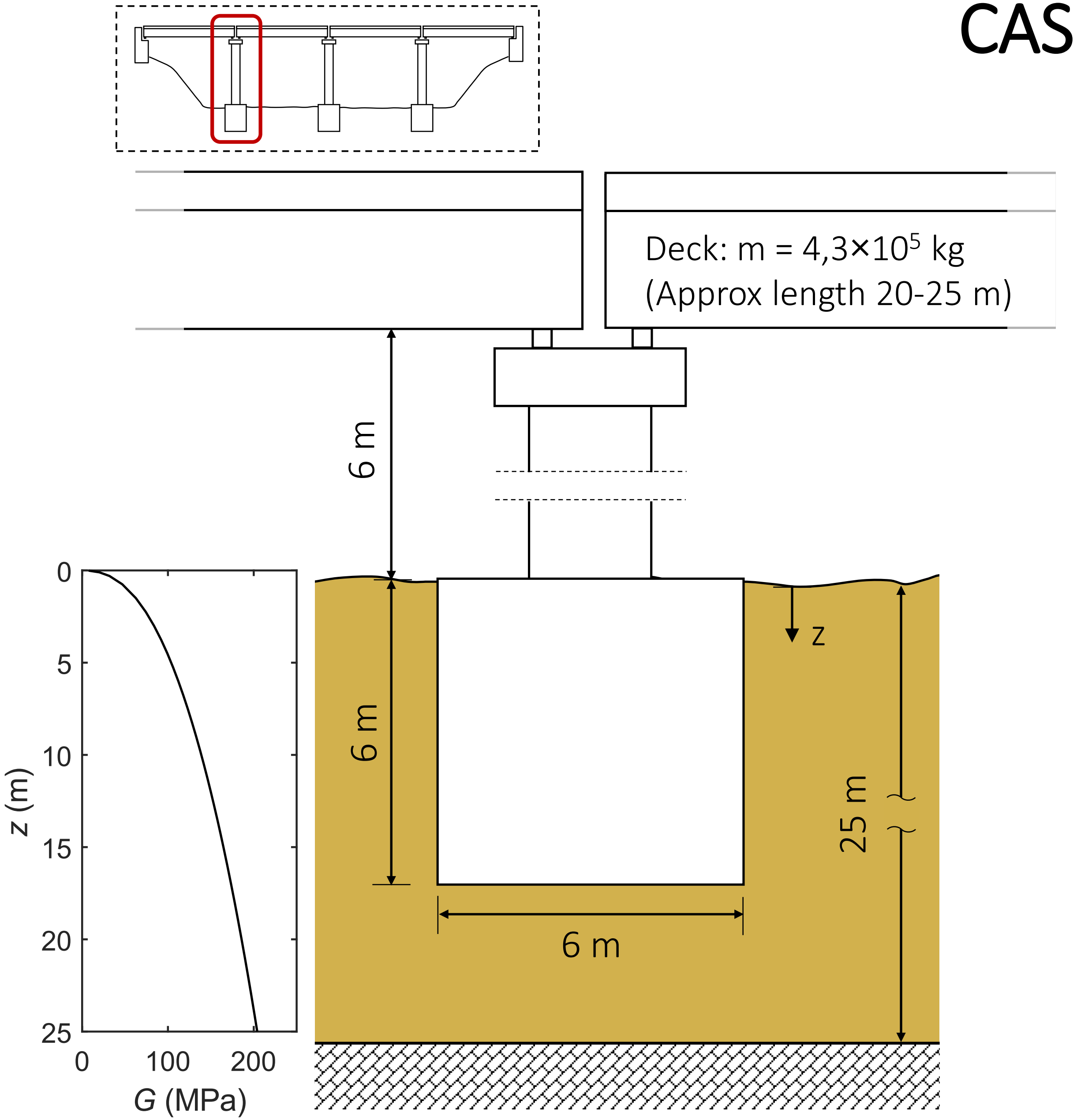
- Proper modeling requires rigorous representation of the problem geometry and adequate constitutive models to reproduce the soil response → **Advanced numerical simulations**

This study presents a **numerical model** to reproduce the dynamic behavior of an **R.C. bridge pier supported on a caisson foundation** embedded in sand, and it estimates the **modal parameters under various local scour scenarios**.

CASE STUDY



Target: circular, full RC pier founded on a cylindrical caisson

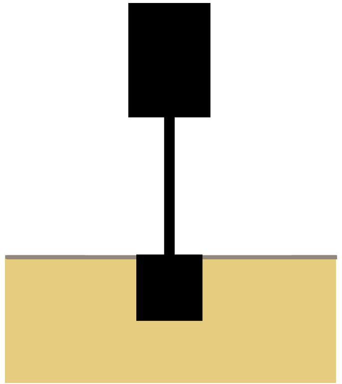
Superstructure: deck composed by simply supported, isostatic, RC beams

→ Pier modeled as a SDOF system

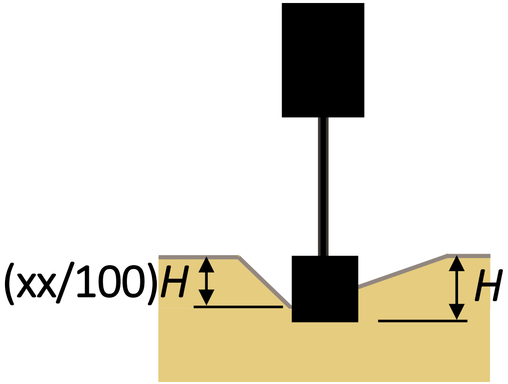
Soil: dense homogeneous sand, characterized in terms of $G(z)$ profile (parabolic type)

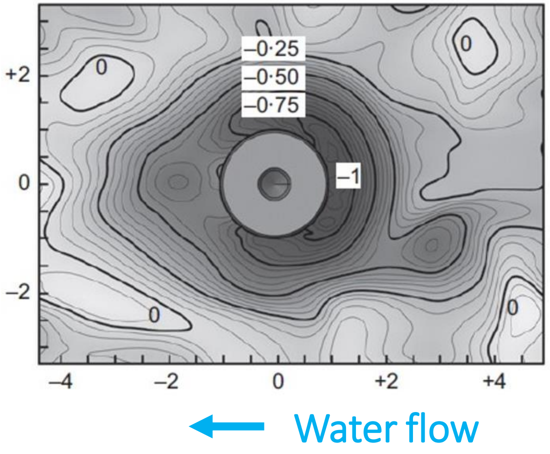
CASE STUDY

Full embedded
"S00"



Local scour scenarios "Sxx"
"S38"; "S50"; "S63"; "S75"





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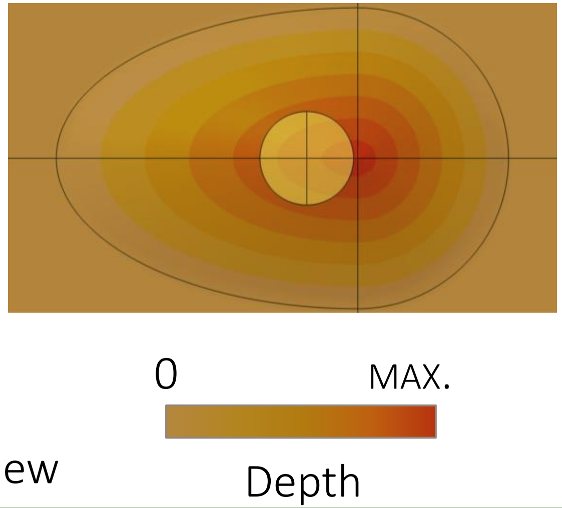


Top view

Target: circular, full RC pier founded on a cylindrical caisson

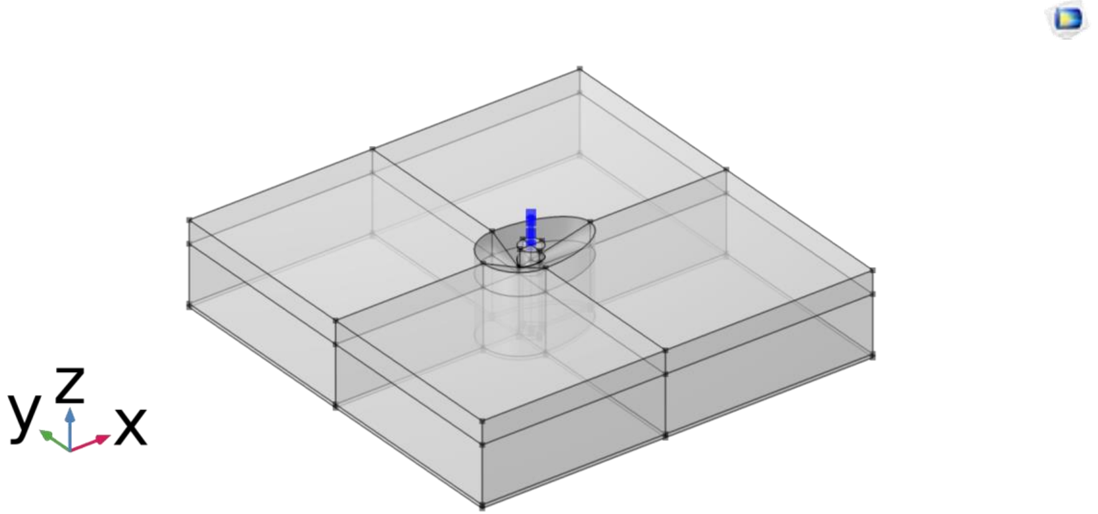
Superstructure: deck composed by simply supported, isostatic, RC beams

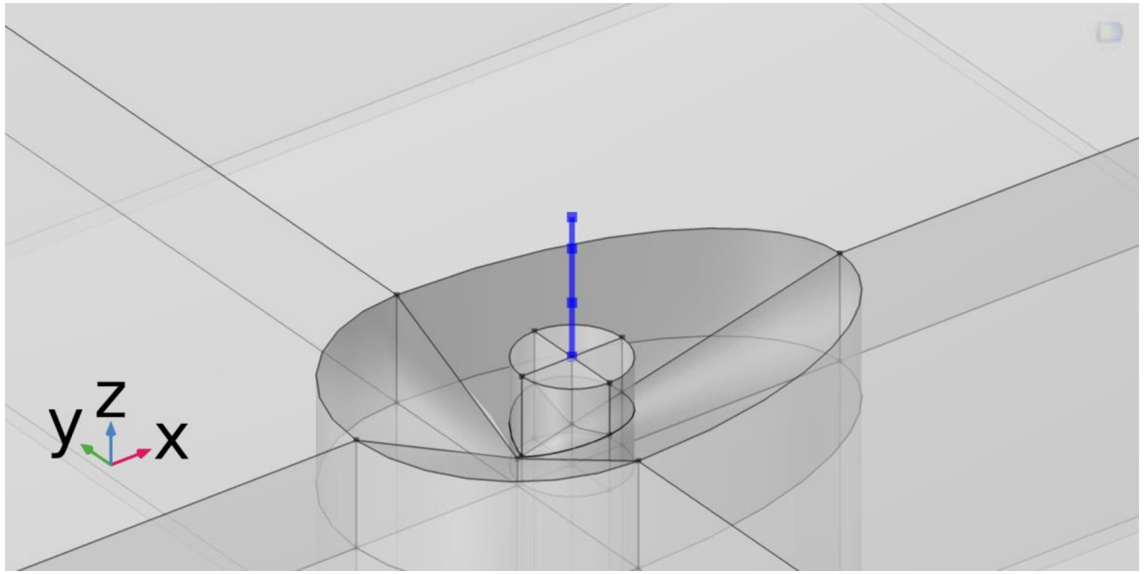
→ Pier modeled as a SDOF system

Soil: dense homogeneous sand, characterized in terms of $G(z)$ profile (parabolic type)

Scour: the dynamic response of the system is addressed considering the foundation fully embedded ("S00") and four local scour scenarios ("S38" to "S75"), with a standard shape of the scour hole

NUMERICAL MODEL – GEOMETRY AND MATERIALS





Structural Mechanics Module of the COMSOL Multiphysics® software.

Deck (mass) → Beam interface (Euler-Bernoulli beams), introduced as a Rigid Domain

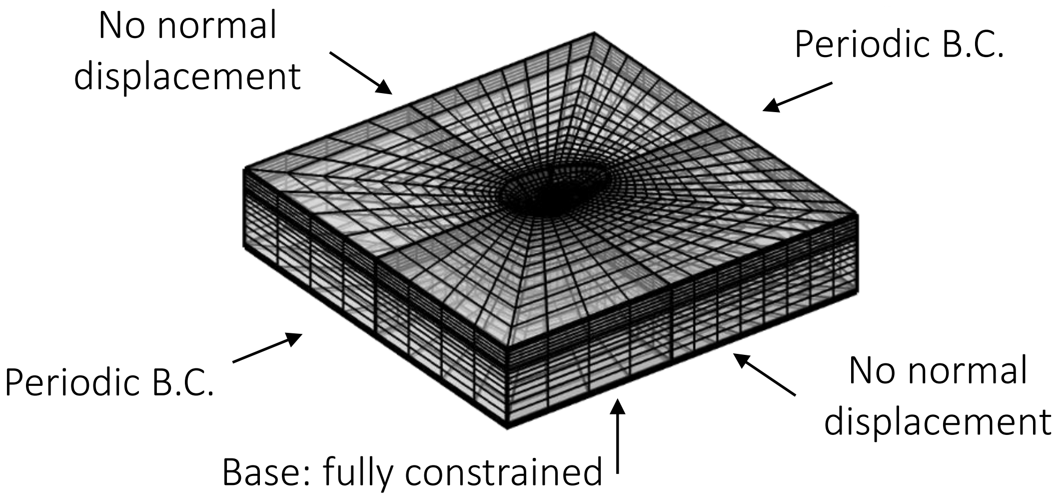
Pier → Beam interface (Euler-Bernoulli beams)

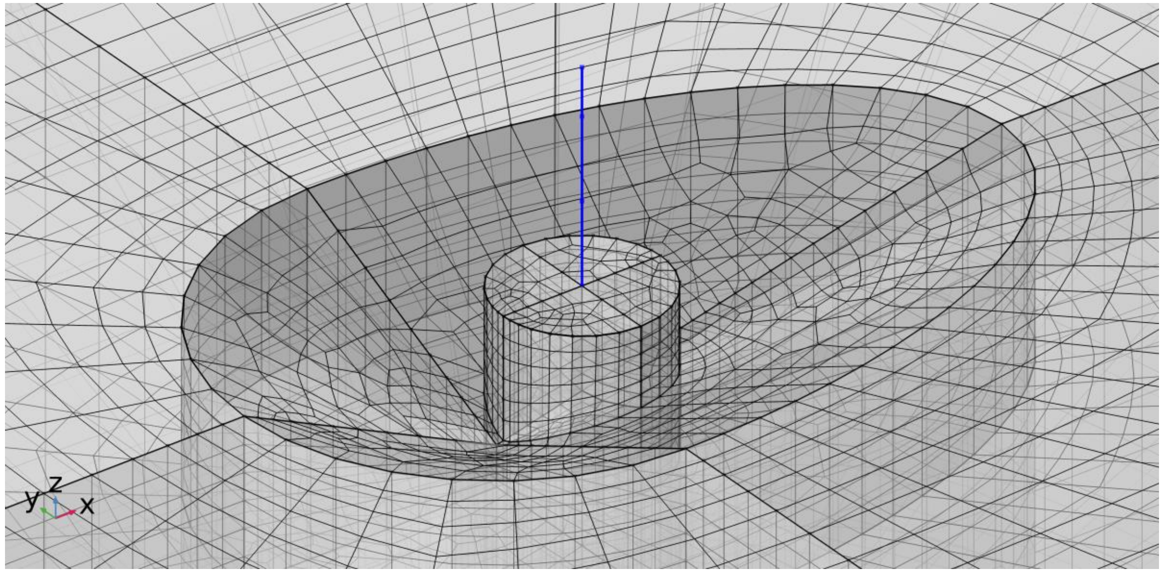
Caisson foundation → Solid Mechanics interface, linked with the superstructure by a Solid-Beam Connection node.

Sand deposit → Solid Mechanics interface, as L×W×D = 75×75×25 m box. For simplicity, also the soil was modeled as isotropic linear elastic, with a Weak Contribution node to update stiffness as a function of the confining pressure.

Foundation scour is introduced by removing a portion of the soil from the sides of the caisson to create an excavation, using the available Boolean operations and solid primitives.

NUMERICAL MODEL – BOUNDARY CONDITIONS AND MESH





Boundary conditions

The boundary conditions force pure shear deformation in the soil deposit, which occurs when affected by the vertical propagation of horizontally polarized shear waves (common scenario in geotechnical earthquake engineering).

Mesh

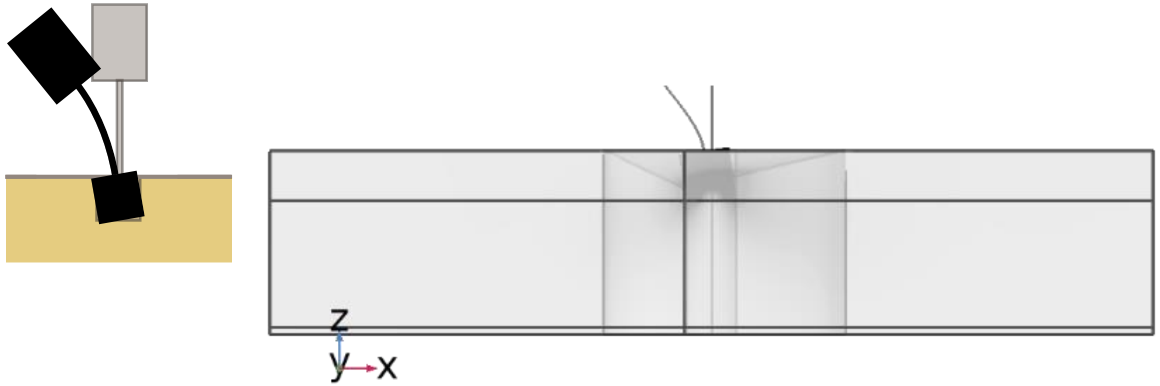
Partially structured mesh with hexahedron elements

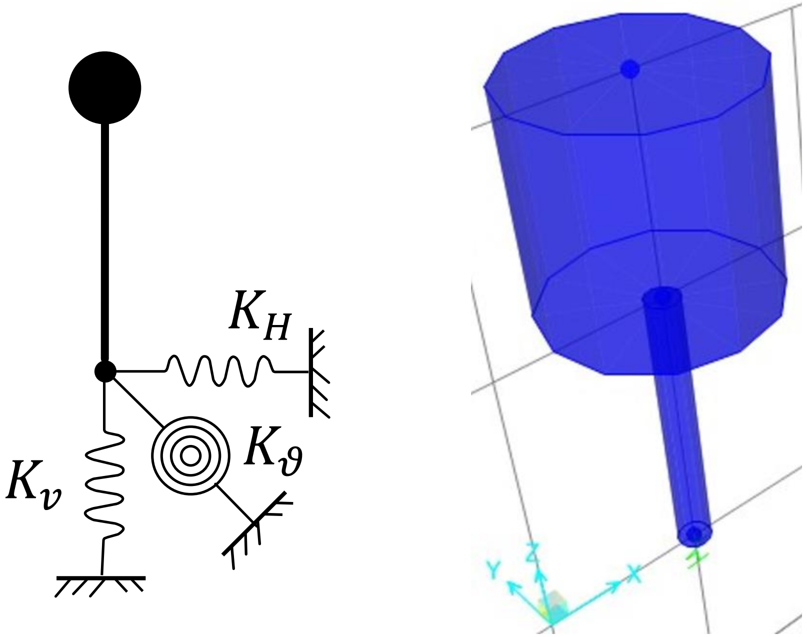
- Scour hole footprint discretized through an unstructured quadrilateral mesh
- Structured mesh on the external region, with exponential growth of the element size

→ 15,000 elements, with adequate element density close to the caisson

Analyses: Eigenfrequency study

NUMERICAL MODEL – VALIDATION





Scenario: <u>fully embedded ("S0") configuration</u>

First rocking mode of the caisson-pier system

<u>Benchmark</u>: soil-structure FE model on SAP2000, with SDOF supported by a set of springs and dashpots applied at the base of the caisson (Gazetas, 1991).

In both cases, the eigenfrequency equals 2.9 Hz → ✔

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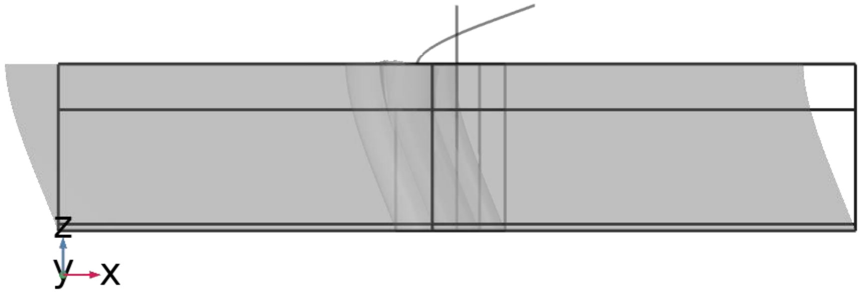

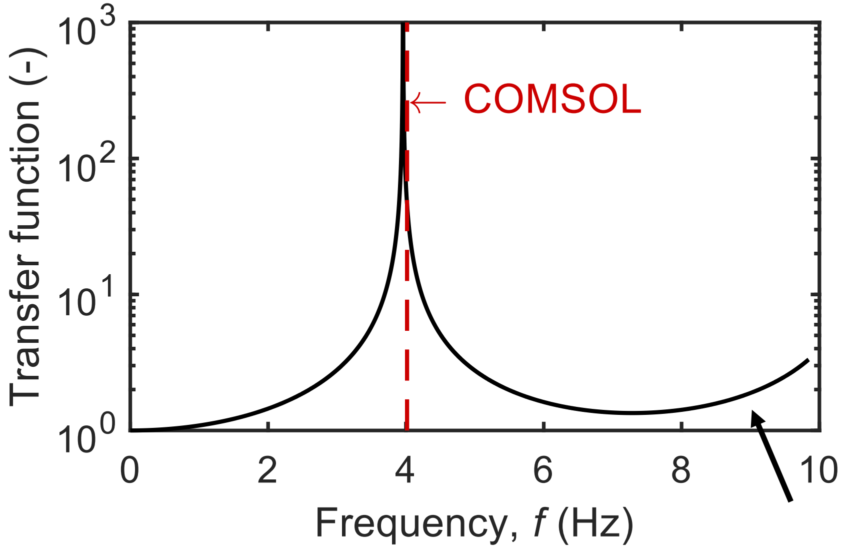

DEEPSOIL V 7.0

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First shear mode of the sand deposit

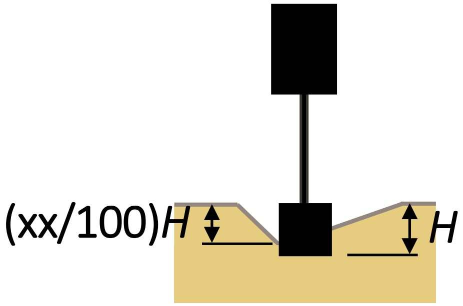
<u>Benchmark</u>: peak of the soil deposit shear-mode transfer function predicted by the Deepsoil software.

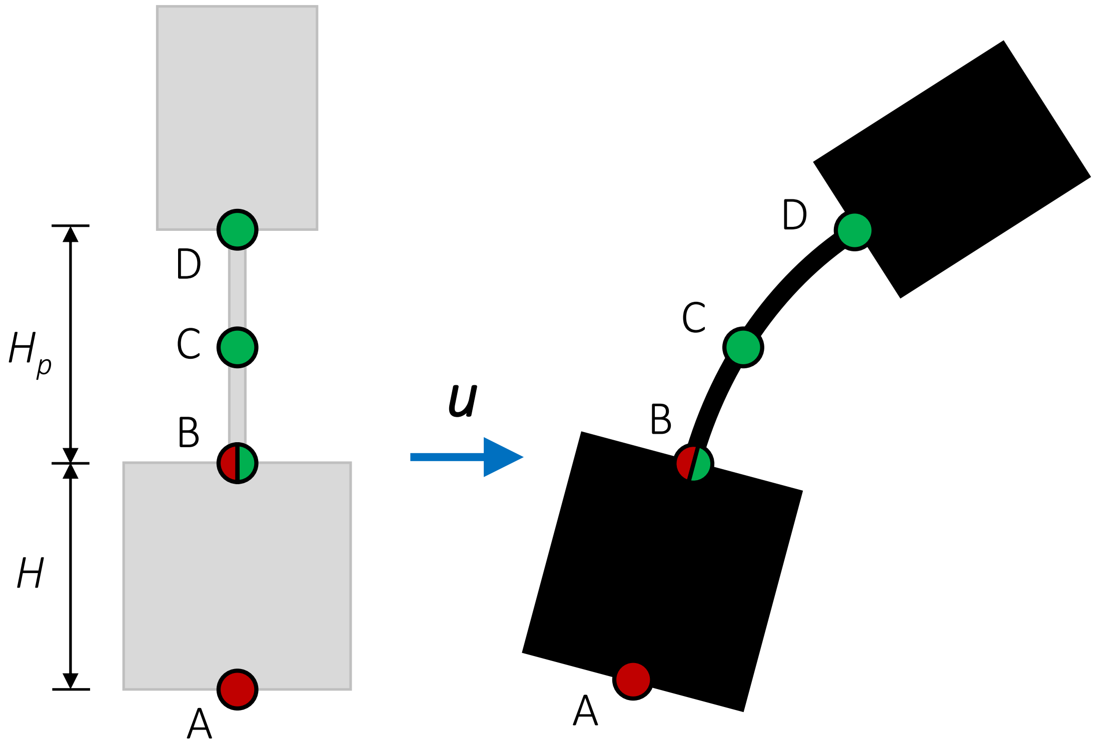
In both cases, the eigenfrequency equals 4.0 Hz → ✔

PARAMETRIC STUDY

Local scour scenarios "Sxx"

"S38"; "S50"; "S63"; "S75"





Focus: first rocking mode

- Eigenfrequency
- Modal shape descriptors
  - Foundation rotation ϑ

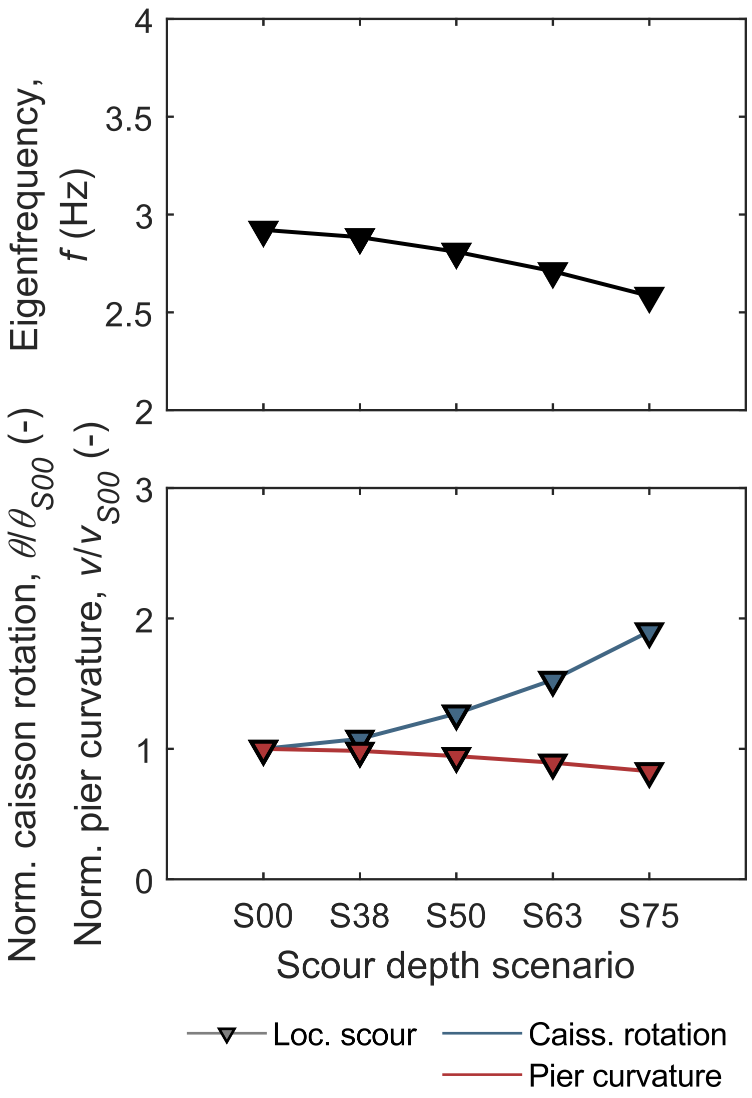
$$\vartheta = \frac{u_B - u_A}{H}$$

  - Pier curvature ν

$$\nu = \frac{u_D - 2u_C + u_B}{H_p^2}$$

All these parameters were normalized with respect to the fully embedded ("S00") configuration, to better appreciate scour-related variations in the modal response.

PARAMETRIC STUDY



Influence of local scour

- The presence of a deeper scour hole results in a reduced eigenfrequency and a large increase in the caisson rotation, up to 50%. The concavity of the trend suggests stronger changes for deeper scour hole scenarios.
- This is partially compensated by a smaller curvature in the pier.

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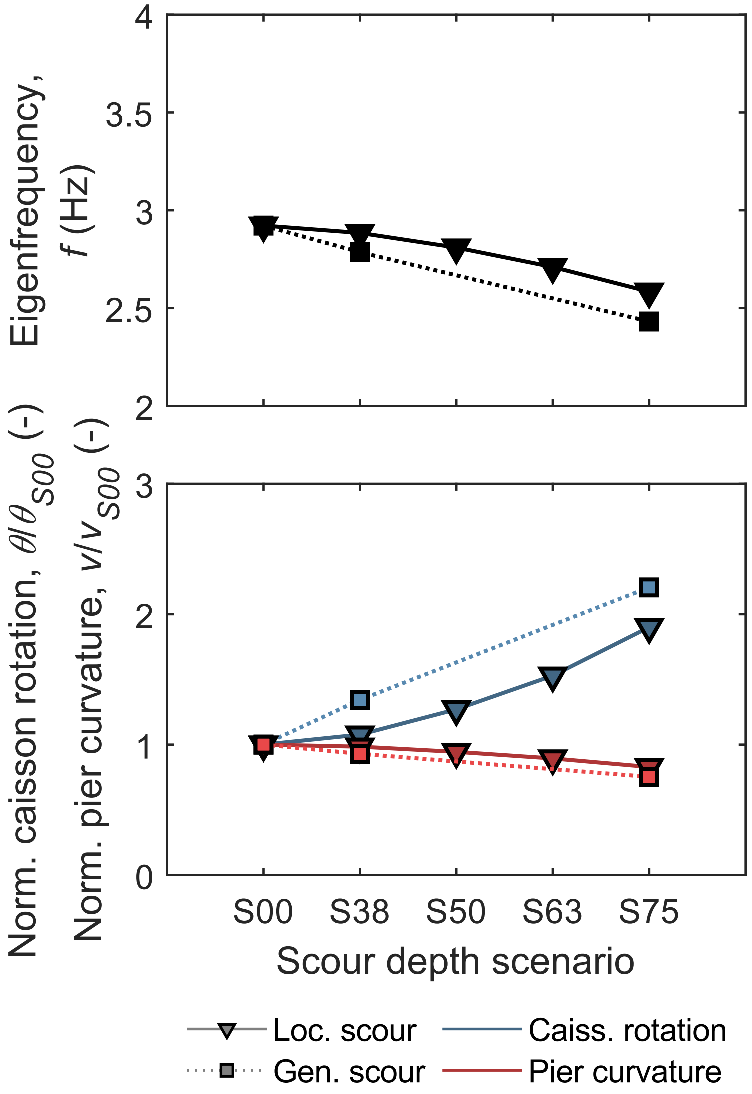

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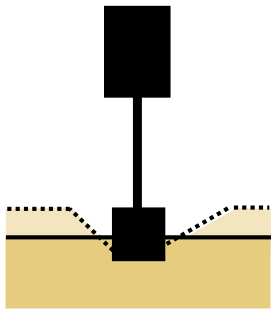
Comparison with "general scour" scenarios = uniform lowering of the ground surface → larger variations in both eigenfrequencies and mode shape parameters.



FINAL REMARKS

- This study has addressed the influence of **local scour** on the **modal response** of a bridge pier supported by a caisson foundation.
- The numerical model was **validated** against alternative numerical schemes, with reference to the first rocking mode of the pier-caisson system and the first shear mode of the soil deposit.
- Then, a parametric analysis highlighted a **reduction of the system eigenfrequencies** and an **increase of base rotations**, with a simultaneous **slight decrease of pier curvature** with increasing scour depth. Furthermore, using simpler representations of the geometry would result in misleading estimates in terms of the dynamic response.
- The study highlights the importance of **properly modeling the hydraulic scenario** when dealing with the dynamic response of bridge piers under scour and the **potentialities of the COMSOL software** to deal with this kind of problems.

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THANK YOU FOR YOUR KIND ATTENTION!

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