COMITÉ FRANÇAIS DE MÉCANIQUE DES SOLS ET DE GÉOTECHNIQUE

Charles-Augustin COULOMB - A geotechnical tribute

Paris, september 25 & 26, 2023

Workshop #1: Design methods for retaining walls

The finite element method and embedded walls

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Outline

Introduction

What is in the simulations

And what is not…

Current level of confidence and accuracy

A few more complex cases

Perspectives

Introduction

The finite element method (FEM) is very widely used for embedded walls
other approaches: analytical models or numerical methods, e.g. subgrade reaction modulus method

For embedded walls, the finite elements are used to perform:

- basically: elastoplastic simulations for service limit states
- more recently: the approach has been extended to c-phi reduction analyses
- in most cases, plane strain (fast, risks of error fairly well identified)

FEM is easy to use, even if remains more complex than other approaches

Introduction

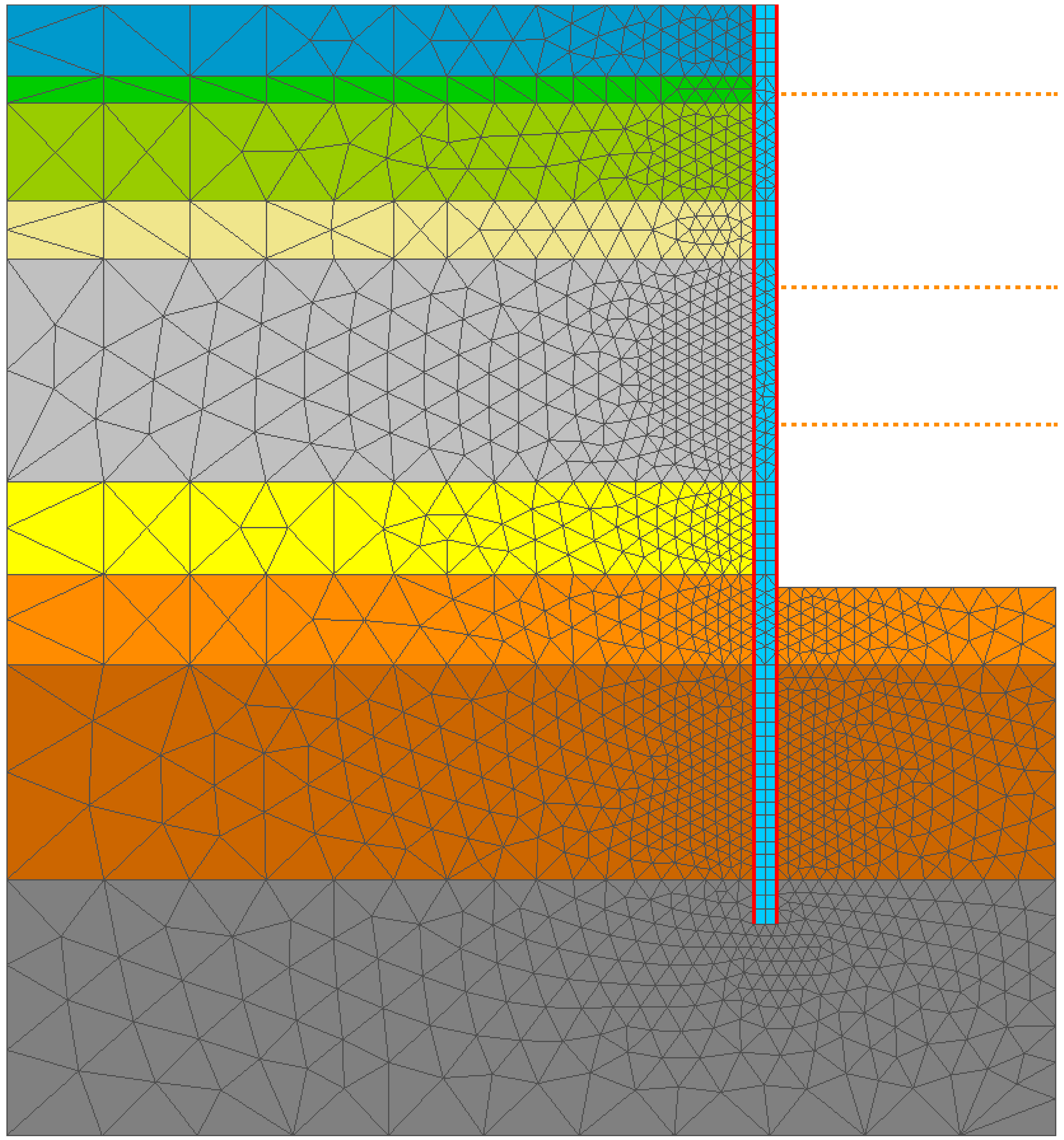
Represent the real problem by partial differential equations

Make choices to build the numerical model:

- plane strain / 3D ?
- beam elements, solid elements, shell elements ?
- choose the constitutive models

Results:

- service state computations:
  - displacements
  - forces in the wall and the supports
- stability analyses: safety factor
  - for each construction step

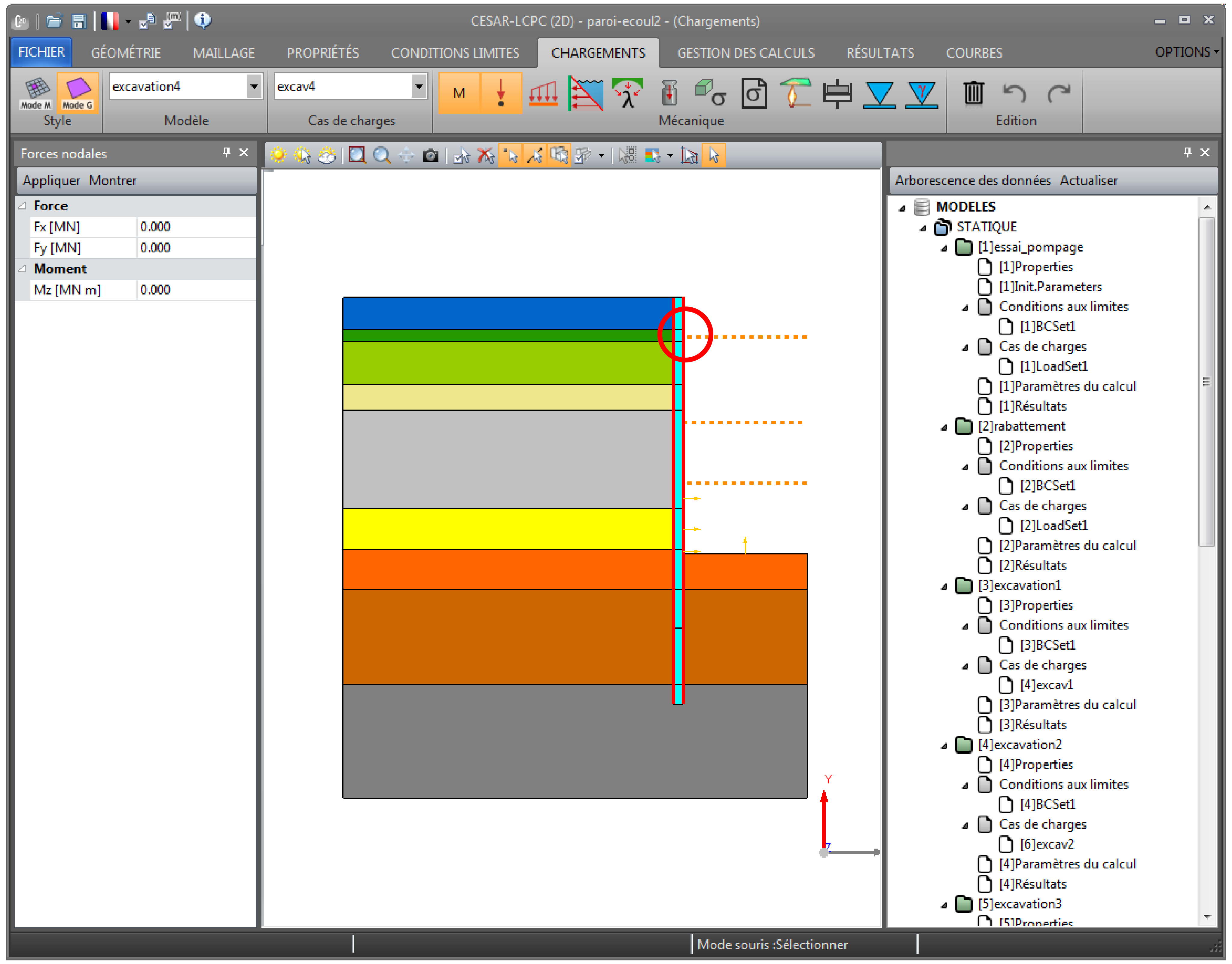


Introduction

A model is a simplification of the real problem

Le Blanc Mesnil station (Grand Paris Express L16)

https://www.batiactu.com/edito/ligne-16-grand-paris-express-se-devoile-58997.php



Is the model not too simple ?

What is in the simulations of embedded walls : five key elements

- the procedure for modelling the excavation process
- the constitutive model:
  a benchmark exercise (Schweiger, 2002) based on data from an actual site,
  compared the relevance of constitutive models
  advanced models (hardening models) are mandatory;
- the ground-wall interface: a specific model is required (even simple)
- the role of the support system
  including pre-tensioning of anchors / props
- water table variations:
  difficult to check the results (lack of appropriate data)

And what is not…

Influence of the wall construction is generally ignored

Local 3D effects and other details are not captured

details of the support system, actual spacing and/or positions of props

cutting of the wall head, actual sequence of the excavation works, temporary loads

Thermal effects (additional loads in props)

Creep in the concrete

Questions that are not easier for embedded walls than in other situations:
unsaturated soils, undrained strength

Current level of accuracy and confidence

Comparison between simulations and experiments shows that

satisfactory results for: wall horizontal displacements

forces / moments in the wall and the supports

the FEM takes into account arching effects in the ground

which can be dominant in some cases (no water in the ground)

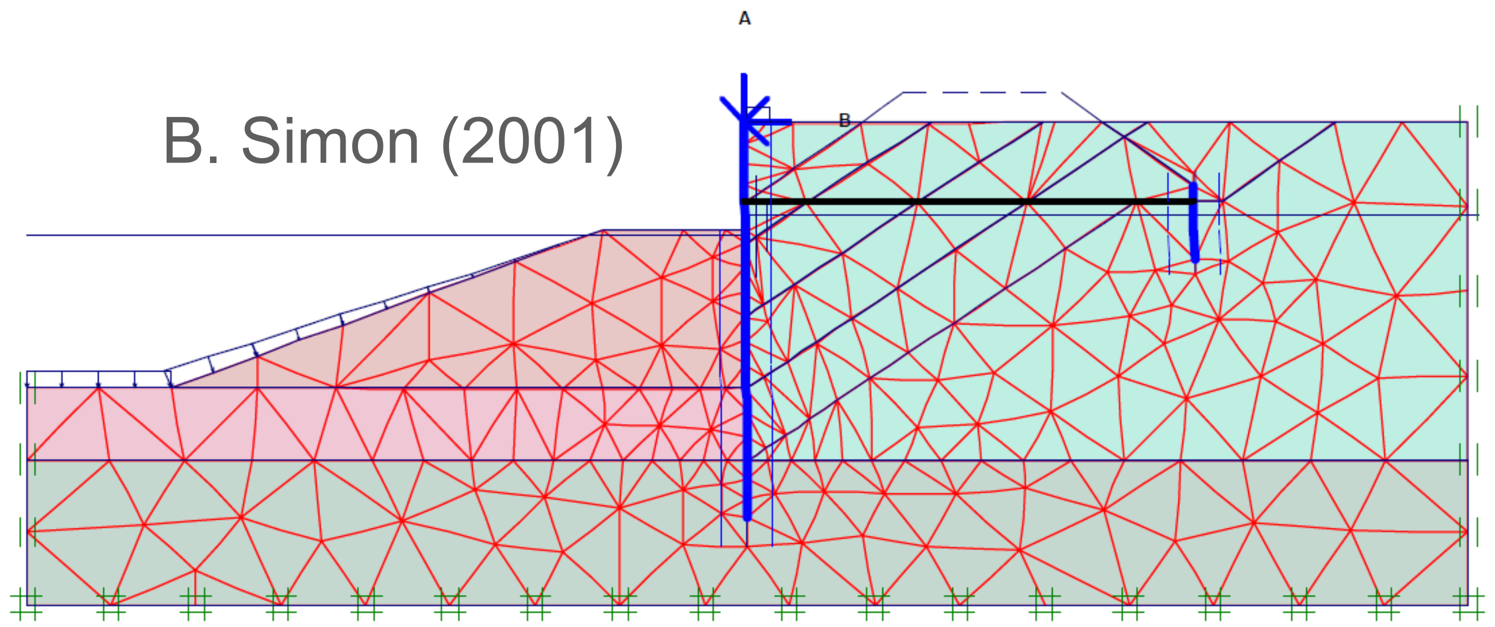
and gives rather more realistic results that the subgrade reaction modulus method

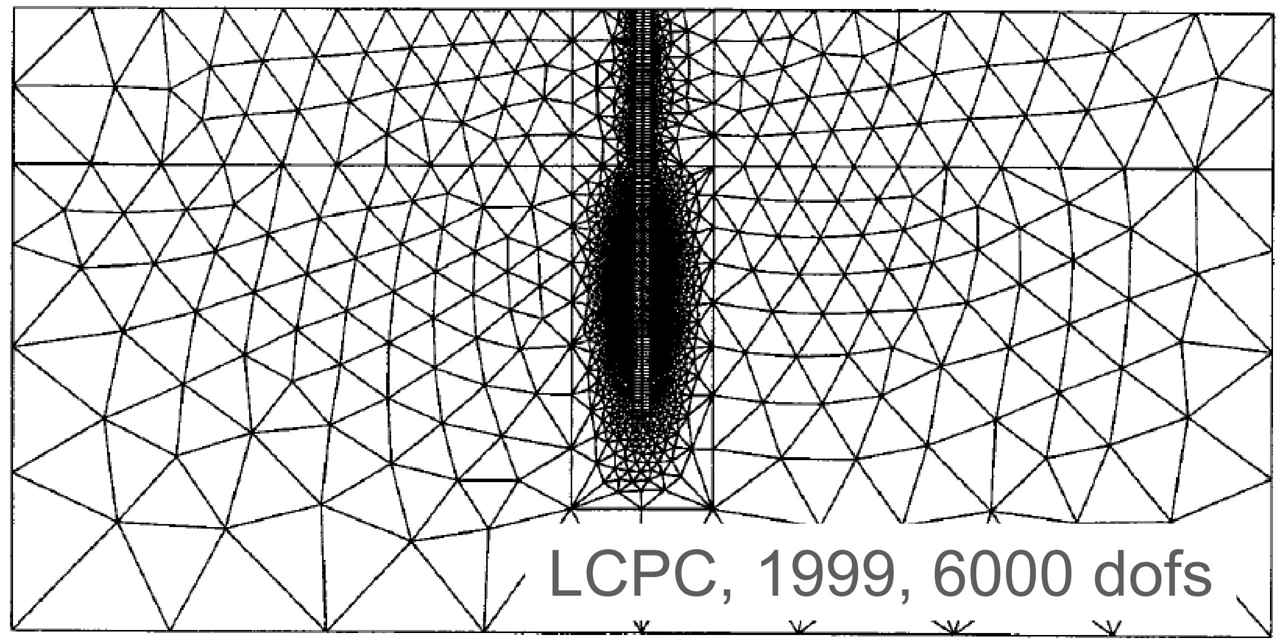
(which tends to underestimate the forces in the props)

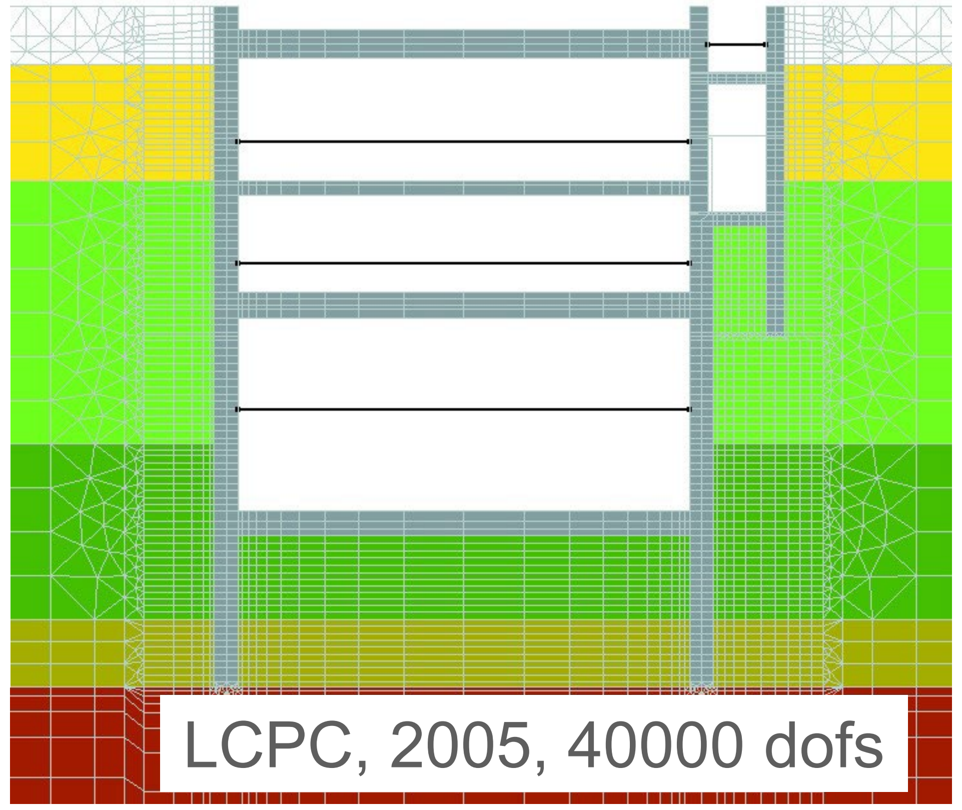
But the FEM uses a « sketchy » representation of some details

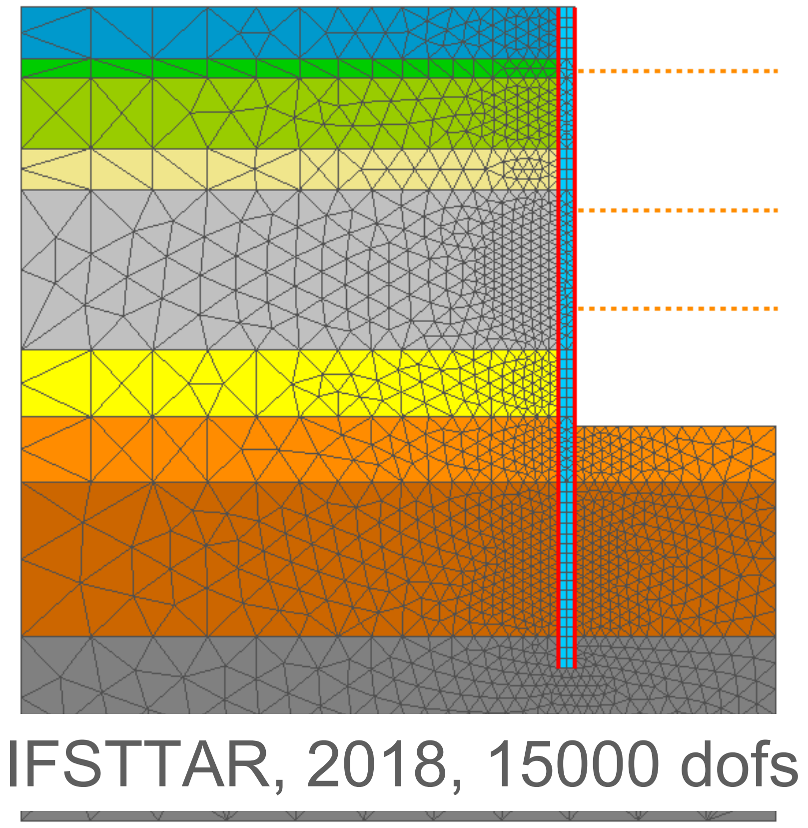
Less confidence regarding settlements behind the wall (few well documented case studies)

About the size of numerical models



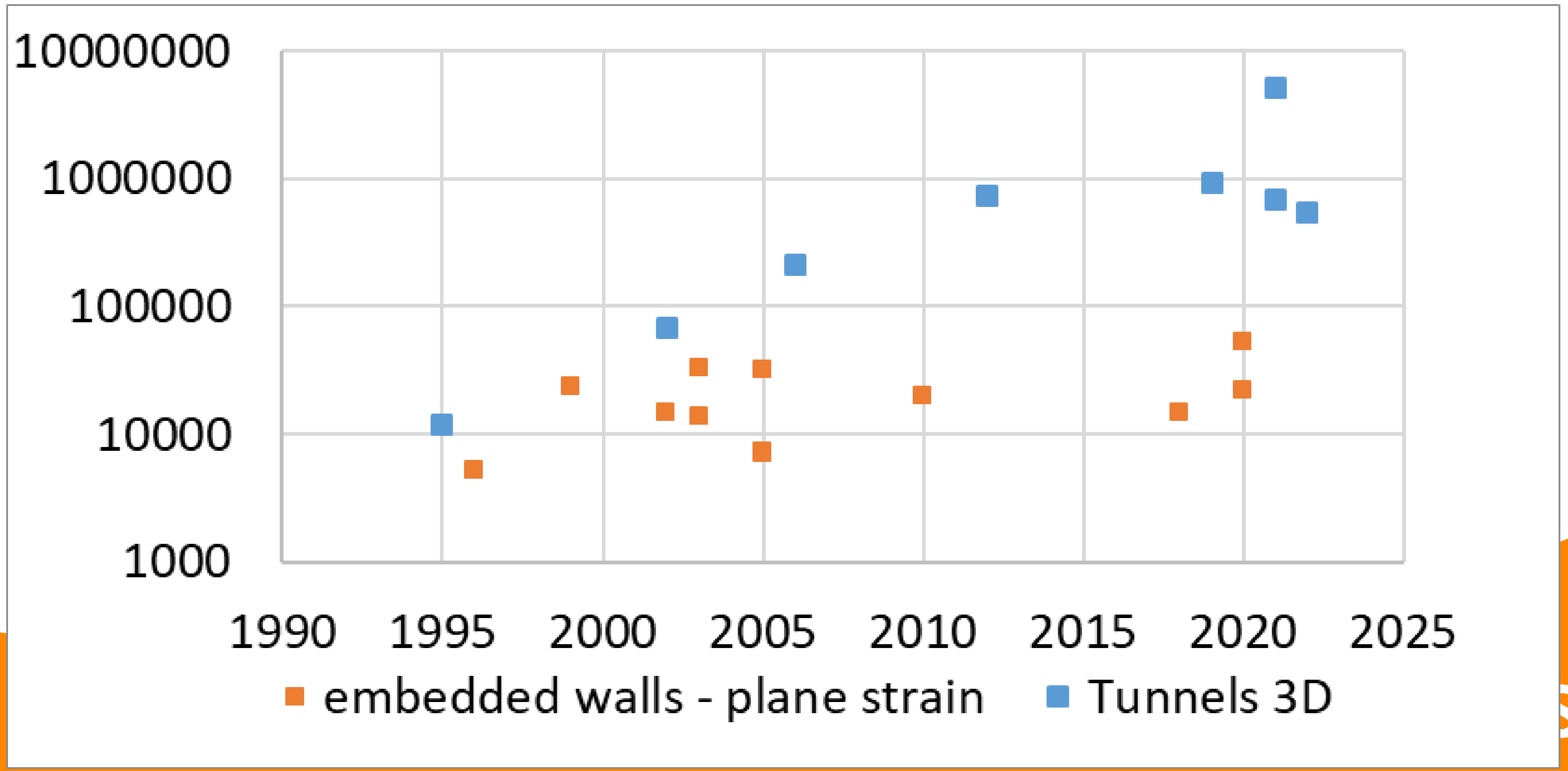






for embedded walls, the size of the numerical problem (in terms of dofs) has increased between 1990 and 2005 but, for plane strain simulations, it no longer increases

for tunnels, 3D models are often necessary: the size of numerical models keeps increasing – the computing power remains a limit (current practice: several millions of dofs)

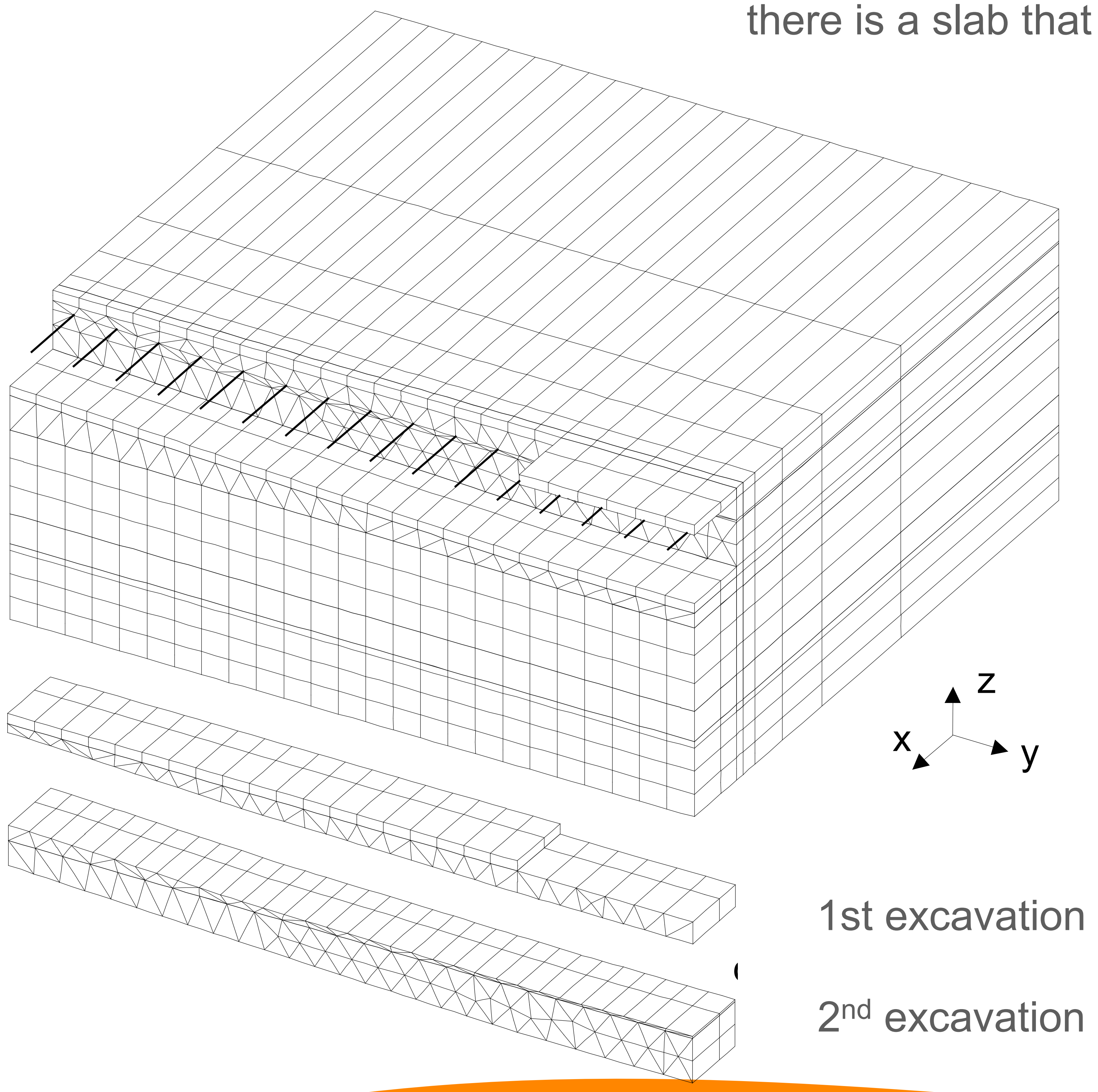


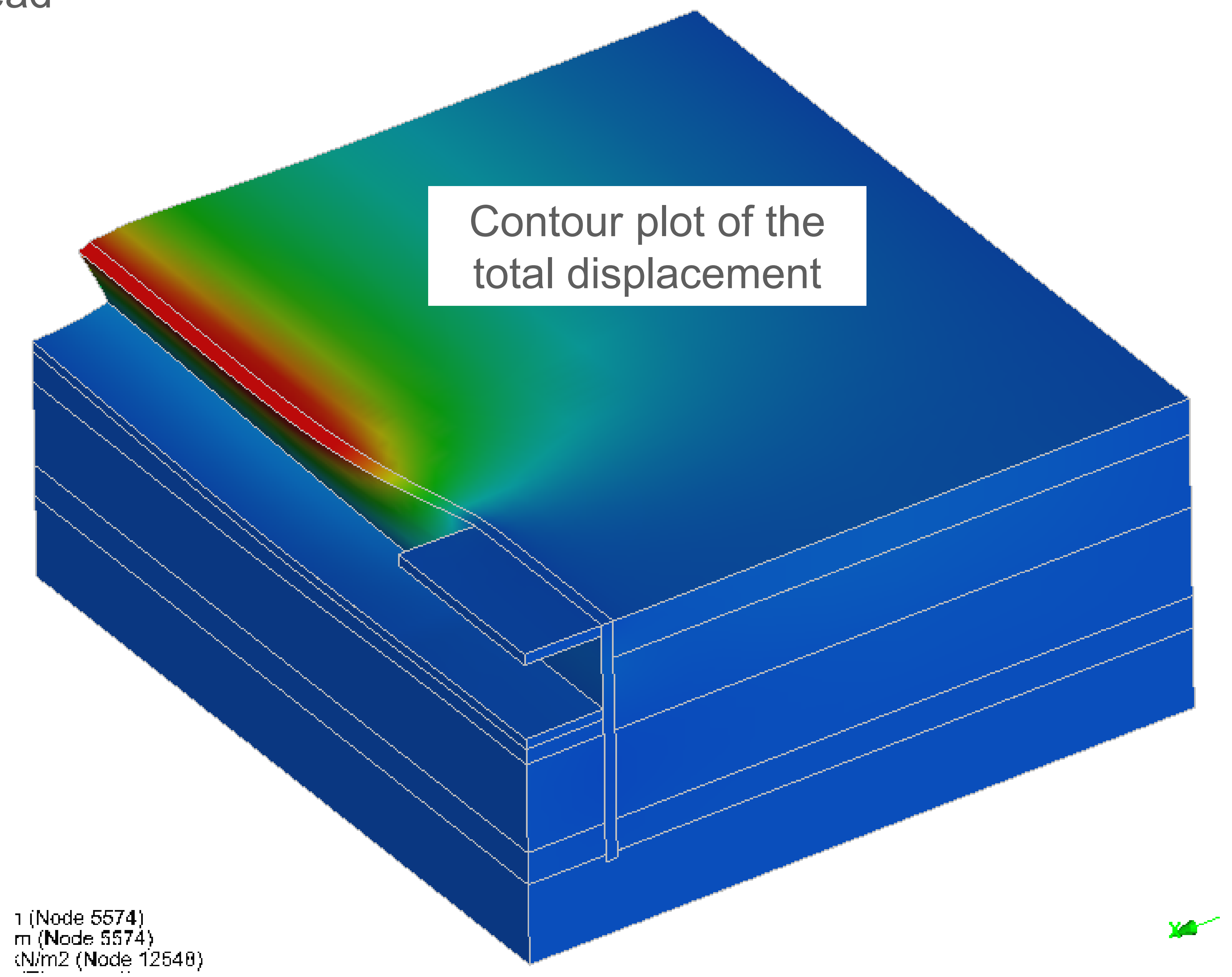
A few more complex cases

Nguyen Phuong Duy (2003) - Trémie Pasteur (Rouen) – 50000 degrees of freedom

the excavation depth varies along the wall

there is a slab that blocks the wall head

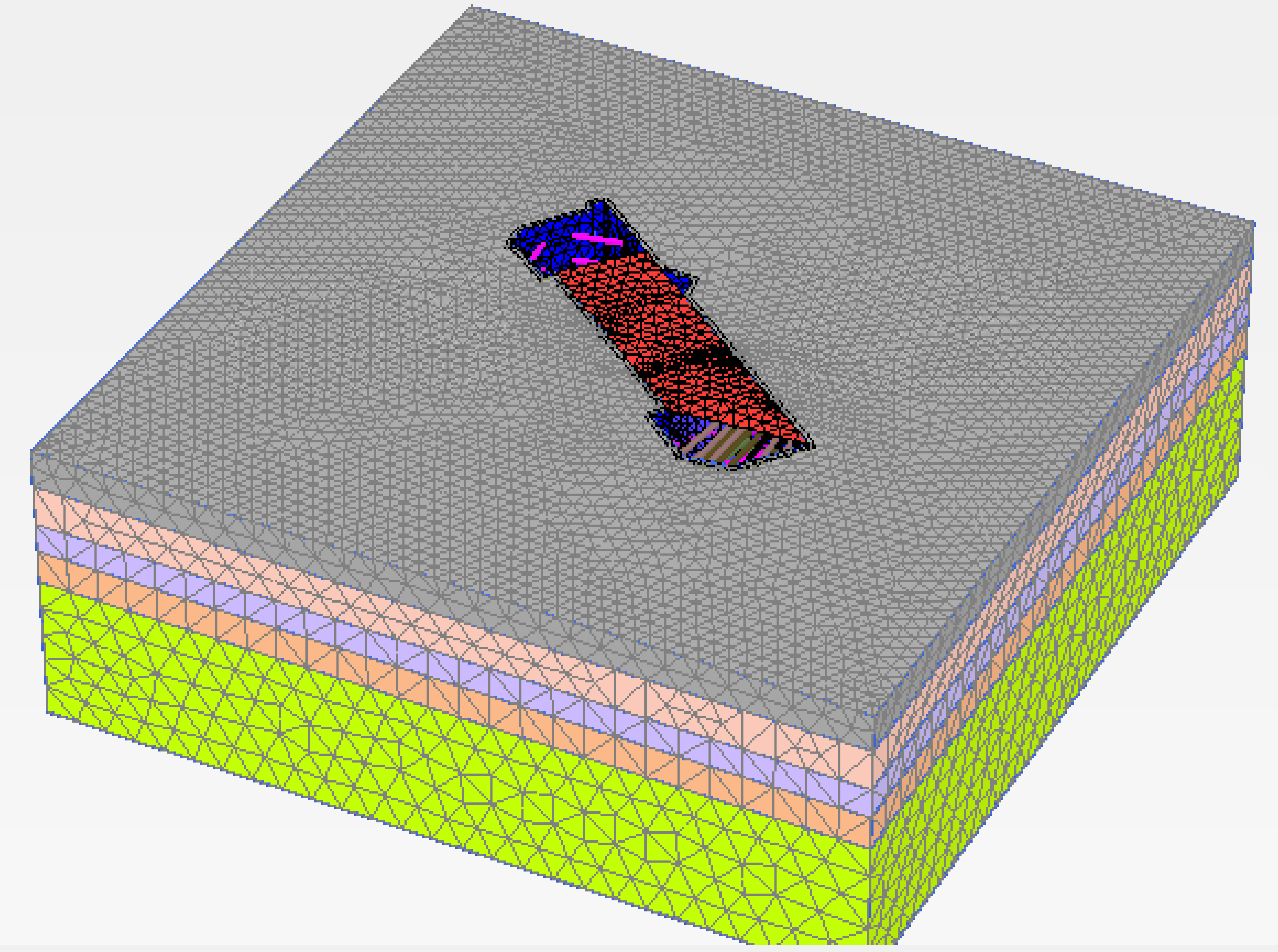


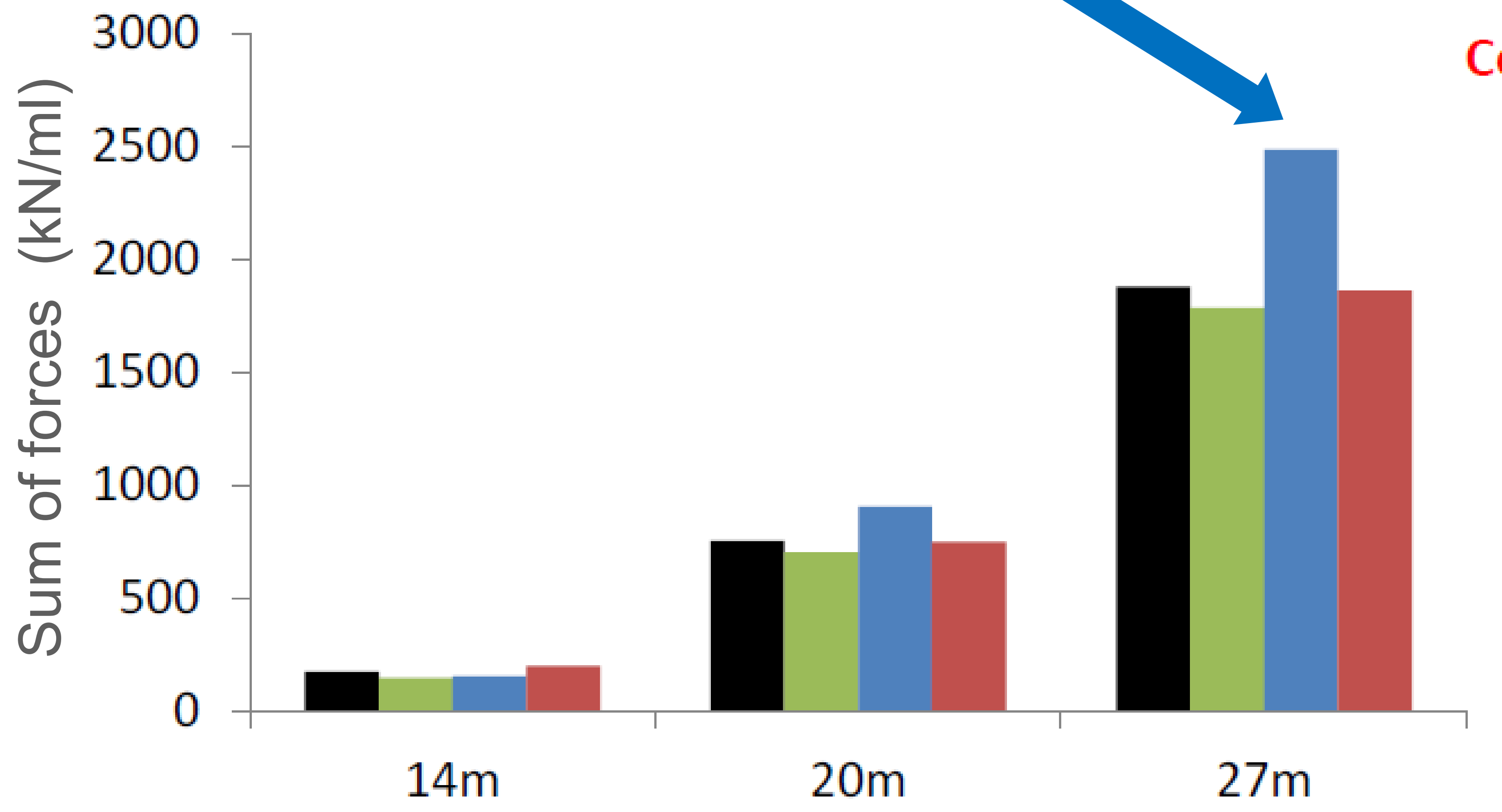


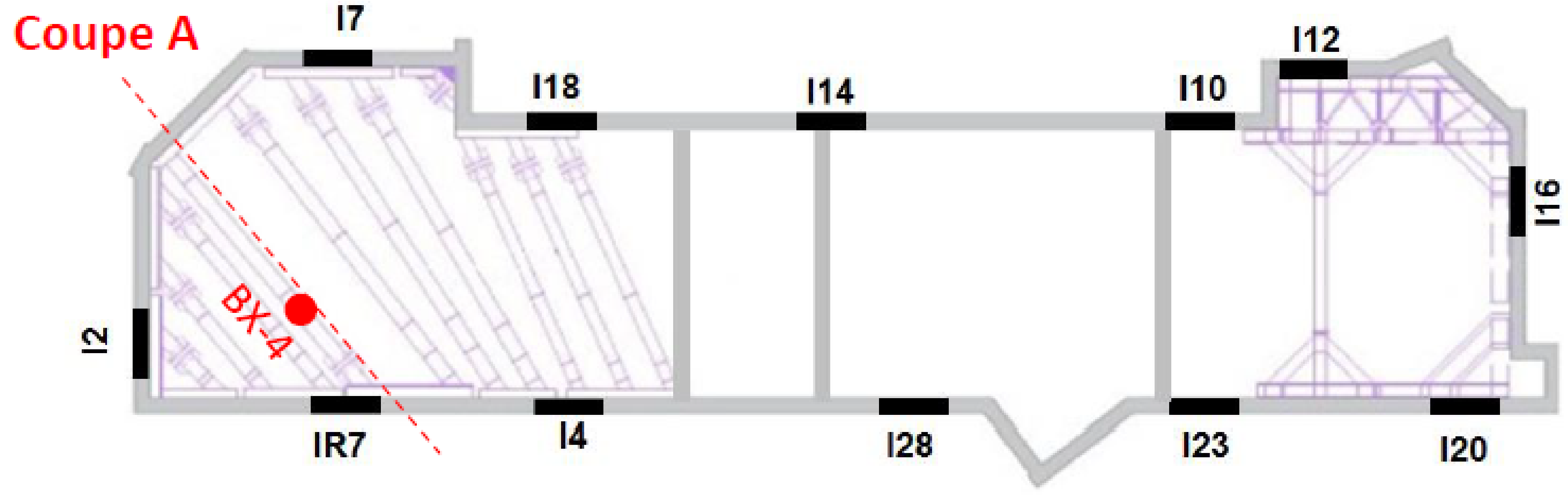
A few more complex cases

Nejjar (2020)
Fort d'Issy-Vanves-Clamart station
of the Grand Paris Express
(~1 million dofs)

For the angle prop, 2D simulations
overestimate the forces



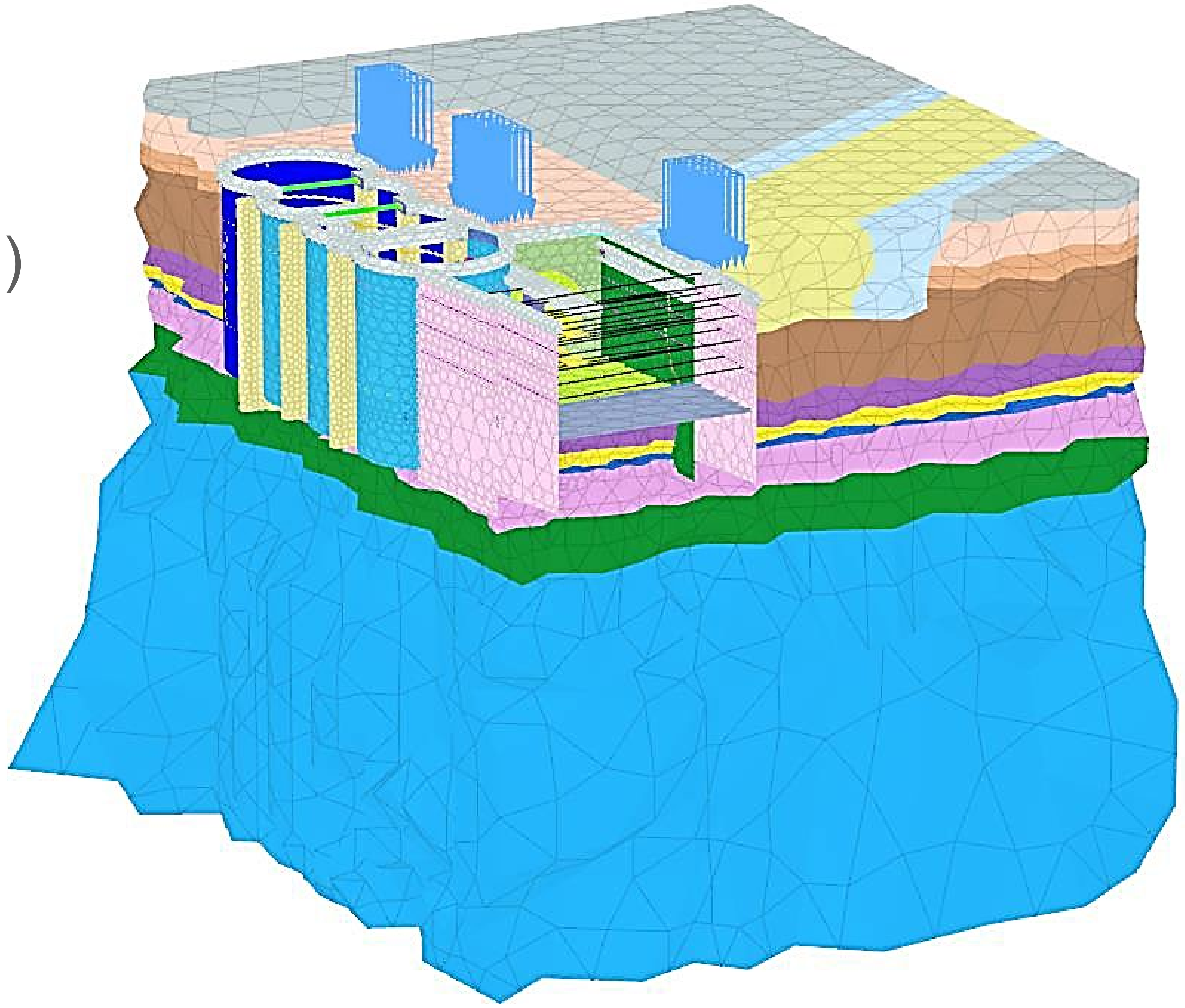


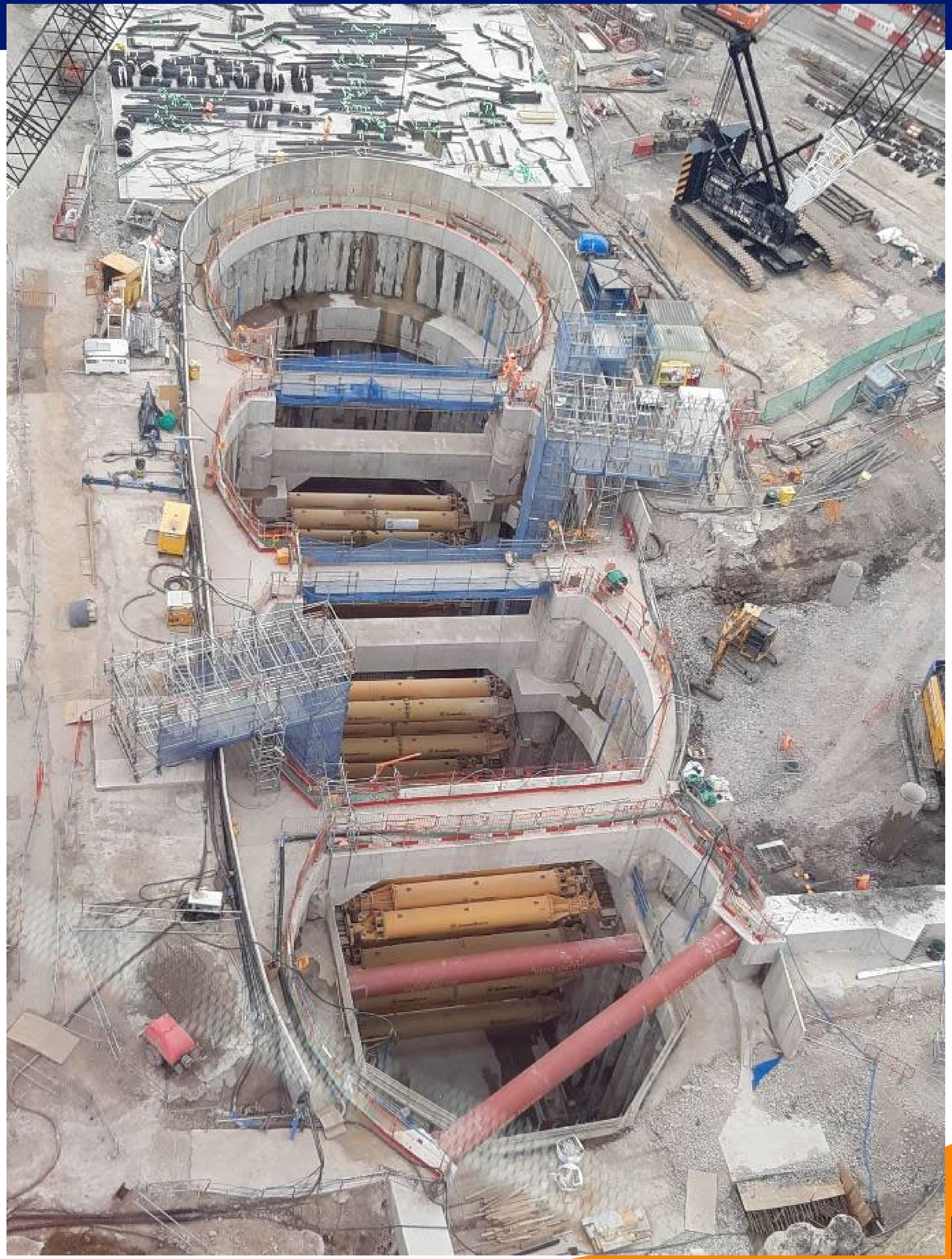


MISS-K EF 2D EF 3D Jauges de déformation

A few more complex cases

Launch Chamber for the Silvertown Tunnel (London)





Martinez-Bacas and Perez-Escacho, NUMGE 2023

Conclusions

Plane strain simulations are used routinely for embedded walls
- the method is robust and reliable
- a certain consensus about how the computations must be carried out
- a few specific questions have not yet been satisfactorily addressed

The approach could be validated because site data are available
- we have less feedback on settlements behind the walls

Monitoring of real structures is of crucial importance to improve the FE models
- the same holds for other techniques (artificial neural networks, deep learning, reduced basis, PGD, etc.)

Perspectives

Is there a need for more complex constitutive models?

no clear trend at the moment (advanced models imply difficulties in parameter identification) but the discussion is not closed

What can 3D models bring?

- improve the understanding of the impact of wall construction
- better simulate the actual construction phases and the details of the geometry

How can our tools evolve?

- improve ergonomy to make computations easier to perform, and results easier to check
- towards design tools rather than computation tools:

engineers spend much time tuning their models

automating model correction and refinement (with respect to target values of the wall thickness; wall reinforcement; support system, etc.) would be useful

Can we combine FE simulations with other approaches?

a clear trend to use FEM to constitute the data required by AI tools

THANK YOU FOR YOUR ATTENTION