VIRTUAL TIME CAPSULE PROJECT

TC103: Numerical Methods

Objectives

Encourage a reflection about

1. The past:
   what are the key developments in numerical methods?
2. The present:
   what is the current use of numerical methods?
3. The future:
   what will be the future? How can we improve it?

THE PAST: ACADEMIC ROADMAP

Kazunori FUJISAWA

Constitutive models of Geomaterials

Description of macroscopic soil behavior based on microscopic observation of particle assemblage

Description of macroscopic behavior of particle assemblage

Data-driven numerical modeling

Computational multiscale modeling, Homogenization technique

Mutual complementation between phenomenological model and micromechanics-inspired model

Physical modeling and experiment
Theoretical analysis
Particle coordination number Graph theory Fabric tensor

Numerical analysis, Numerical experiment

Observation and direct description of particle dynamics

Elasto-plasticity

Anisotropy
Rotational hardening, Fabric tensor, Modified stress tensor

Unsaturated soils

Intermediate soils, problem soils, artificial and improved geomaterials
Cement-treated soils, fiber-reinforced soils, bio-stabilization, organic soils, expansive clay, etc.

Application to Geomechanics
Mohr-Coulomb model, Drucker-Prager model, etc.

Over-consolidated soils
Cyclic plasticity
Subloading surface model, Bounding surface model, Multi-surface model

Structured soils, Naturally-deposited soils
Superloading surface model

Liquefaction, Cyclic mobility

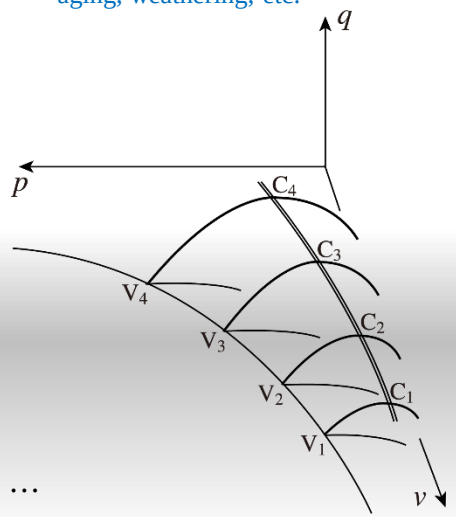
Coupling with thermal effect and chemical reactions
Freeze and thaw, bonding and degradation, aging, weathering, etc.

Critical state soil mechanics
Cam-Clay model

Development of plasticity theory
(since late 18th century)

Visco-plasticity
Perzyna model, etc.

Effect of intermediate principal stress or third stress invariant
Matsuoka–Nakai criterion, Lade–Duncan criterion



Coupling with different class of models

Hypo-plasticity

Computational technique for plasticity
Return-mapping, multiplicative decomposition

Direct representation of stress vs. strain curve

Monotonic behavior Expression based on hyperbolic curve (e.g., Duncan–Chang model)

Cyclic behavior Masing rule and its extension (e.g., RO model, HD model)

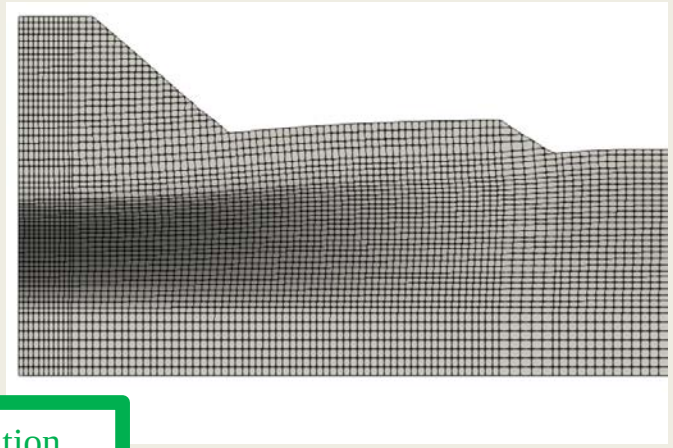
Strategies for description of material nonlinearity

Elasticity

Elasticity (isotropic / anisotropic), Hypo-elasticity, Hyper-elasticity, Visco-elasticity, …

1960 1970 1980 1990 2000 2010 2020 2030

Finite element method (FEM)



Contact and fracture analysis
Micro and macro scales
Fracture/crack growth
Multi-physics
Virtual reality
Heterogeneous problems
Multi-scale problems

Visualization, Design practice

Pre- /post-processing
User-friendly, GUI
CAD, Image Recognition and Image Processing

Expansion of temporal/ spatial scale

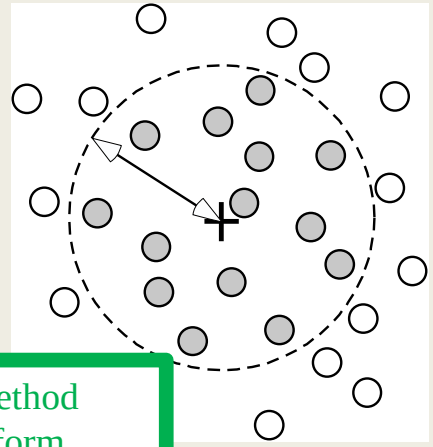
Fast processing algorithms
3D nonlinear analysis (Hayami et al. 1973)
Spread of solver package (PARDISO, LAPACK)
Iterative method (CG, bi-CGSTAB)
Viscosity analysis (Saito et al. 1975)
Contact analysis
Sophistication of interaction model trade-off in refinement of measurement techniques
Dynamic problems (Hayashi et al. 1974)
Reliability analyses
Stochastic FEM

Simulation: High accuracy, Integration

Consolidation analysis (Yokoo et al. 1971)
Finite strain consolidation theory
Limit analysis, Rigid plastic (Tamura et al. 1984)
Seepage analysis (Kawamoto et al. 1971, Kawano et al., 1970)
Integration of static and dynamic analyses
Elasto-plastic analysis (Kobori et al., Yamaguchi, 1970)
Integrated numerical analyses of deformation, fracture and flow

1960 1970 1980 1990 2000 2010 2020 2030

Continuum-based methods other than standard FEM



Other methods

Meshless Method with weak form

Meshless Method with strong form

Finite Volume Method (FVM)

Finite Difference Method (FDM)

Lattice Boltzman Method (LBM)

Material Point Method (MPM)
(Sulsky et al., 1994)

hp-meshless clouds method
(Duarte & Oden, 1996)

Reproducing Kernel Particle Method (RKPM)
(Liu et al., 1995)

The Partition of Unity FEM (PUFEM)
(Melenk &Babuska, 1996)

Meshless local Petrov-Galerkin method (MLPG)
(Atluri & Zhu, 1998)

Element-free Galerkin Method (EFGM)
(Belytschko et al., 1994)

Diffuse Element Method (DEM)
(Nyroles et al., 1992)

Least-squares Collocation Meshless Method
(Zhang et al., 2001)

Point Collocation Method (PCM)

Finite Point Method (FPM)
(Oñate et al., 1996)

Smoothed Particle Hydrodynamics (SPH)
(Gingold & Monaghan, 1977)

Since the late 1980s and early 1990s, the finite volume method has been shown suitable for solid analyses as well as fluid dynamics. A lot of advancements of FVM in solid analyses are currently present.

The usage of FDM for solid analysis is limited compared with fluid analysis. The simplest form of FVM is the same as FDM.

1960 1970 1980 1990 2000 2010 2020 2030

Challenges

Verification and validation with benchmarking.

Enhancement of suitability for large-scale analysis or super computing.

Exhibition and education of the performance of calculation methods.

Code dissemination facilitating ease of understanding and implementation

Multi-scale analysis

Application to design, such as disaster prevention and fracture control

Application to new living spaces and environmental activities.

Discontinuum-based modeling

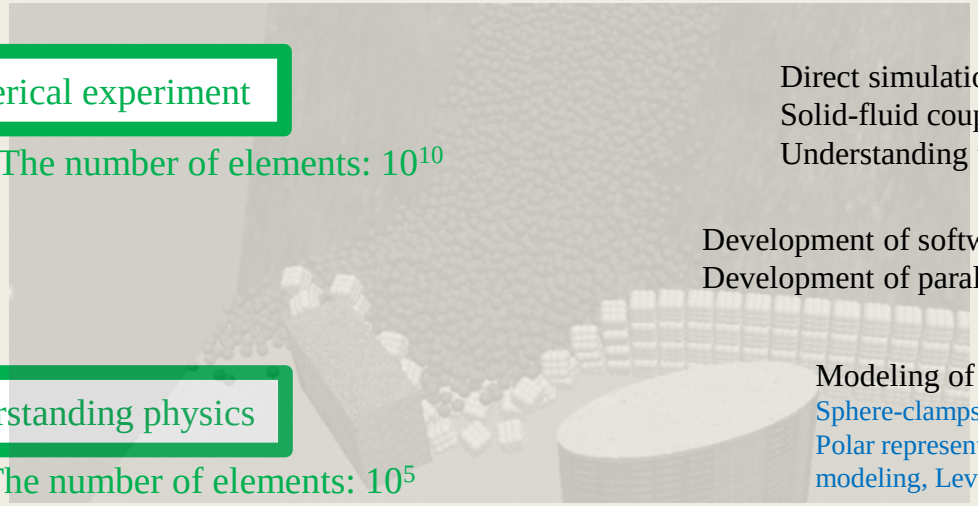
Challenges

Verification and validation with benchmarking.

Suitable and reasonable representation of gain shape and particle size distribution

Multi-scale & multi-physics analysis.

Simulator of laboratory tests.



Numerical experiment

The number of elements: 10^{10}

Direct simulations of granular materials
Solid-fluid coupled analysis
Understanding from micro to macro

Development of softwires
Development of parallel computing

Understanding physics

The number of elements: 10^{5}

Modeling of particle shape
Sphere-clamps, Ellipse-shaped element, Polyhedral element, Polar representation, Voxel-based modeling, NURBS-based modeling, Level set-based modeling

Alogism for first and reasonable contact detection
Contact plane method, Linked-list, level set-based approach

Modeling of phenomena

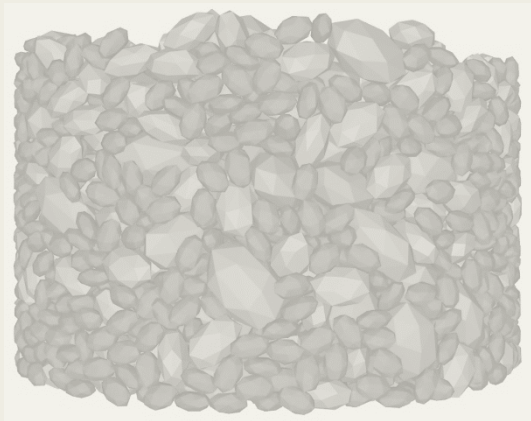
The number of elements: 10^{1}

Numerical Manifold Method (NMM)
(Shi & Goodman, 1984)

Discontinuous Deformation Analysis (DDA)
(Shi & Goodman, 1984, Shi 1988)

Rigid Bodies-Spring Model (RBSM)
(Cundall, 1971, Cundall and Strack 1979)

Discrete Element Method (DEM)
(Cundall, 1971, Cundall and Strack 1979)



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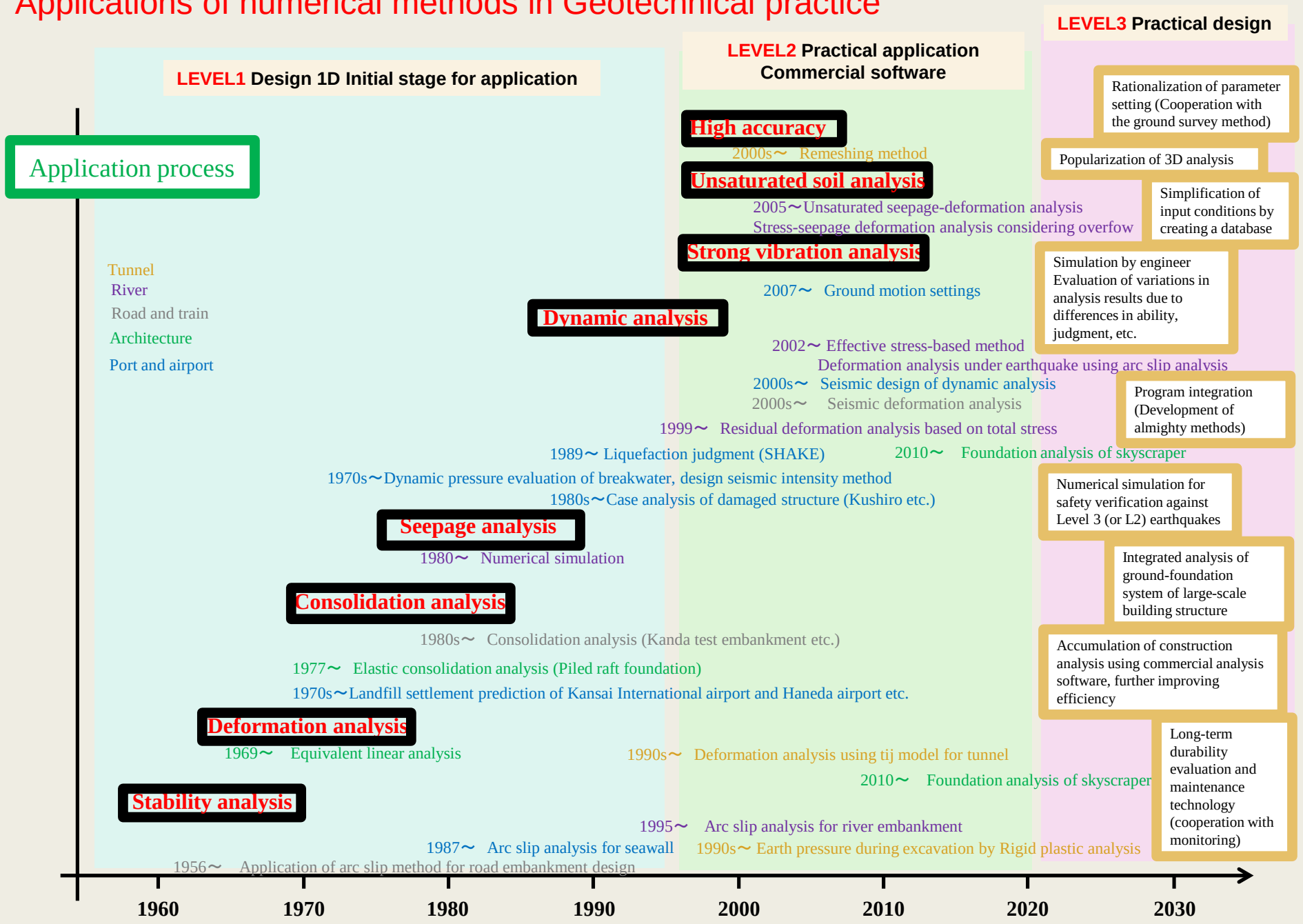
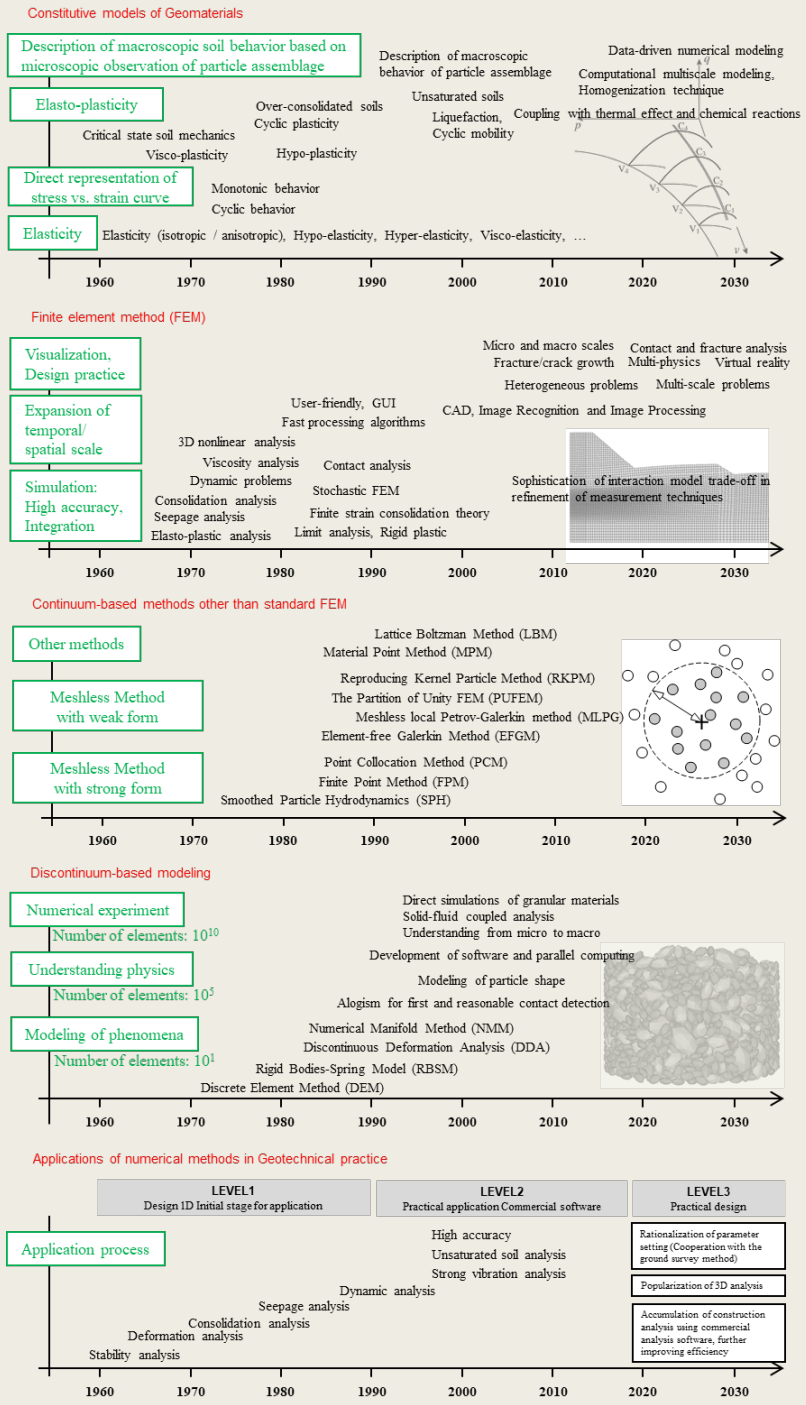
Applications of numerical methods in Geotechnical practice



Summary of academic roadmap



Summary of academic roadmap (One-page article) is available at the following link.

https://drive.google.com/file/d/1yaTZ9BJgtl_EErs5qCrqL8lVRjwH0nnR/view?usp=sharing

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Continuum-based methods other than standard FEM

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Discontinuum-based modeling

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Applications of numerical methods in geotechnical practice

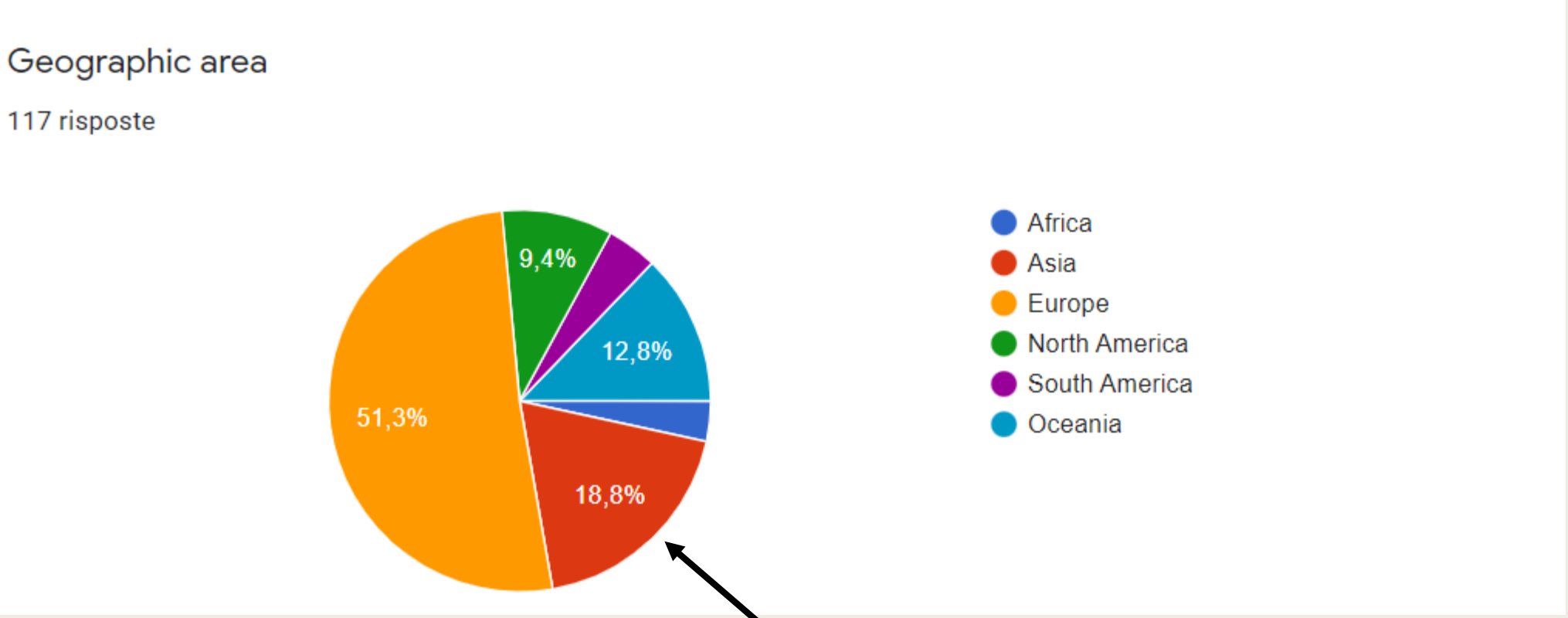
- Kazuhiro KANEDA
- Koji ICHII
- Hidekatsu TAKEUCHI
- Tsuyoshi HONDA

THE PRESENT: QUESTIONNAIRE

Francesca Ceccato

Results: people

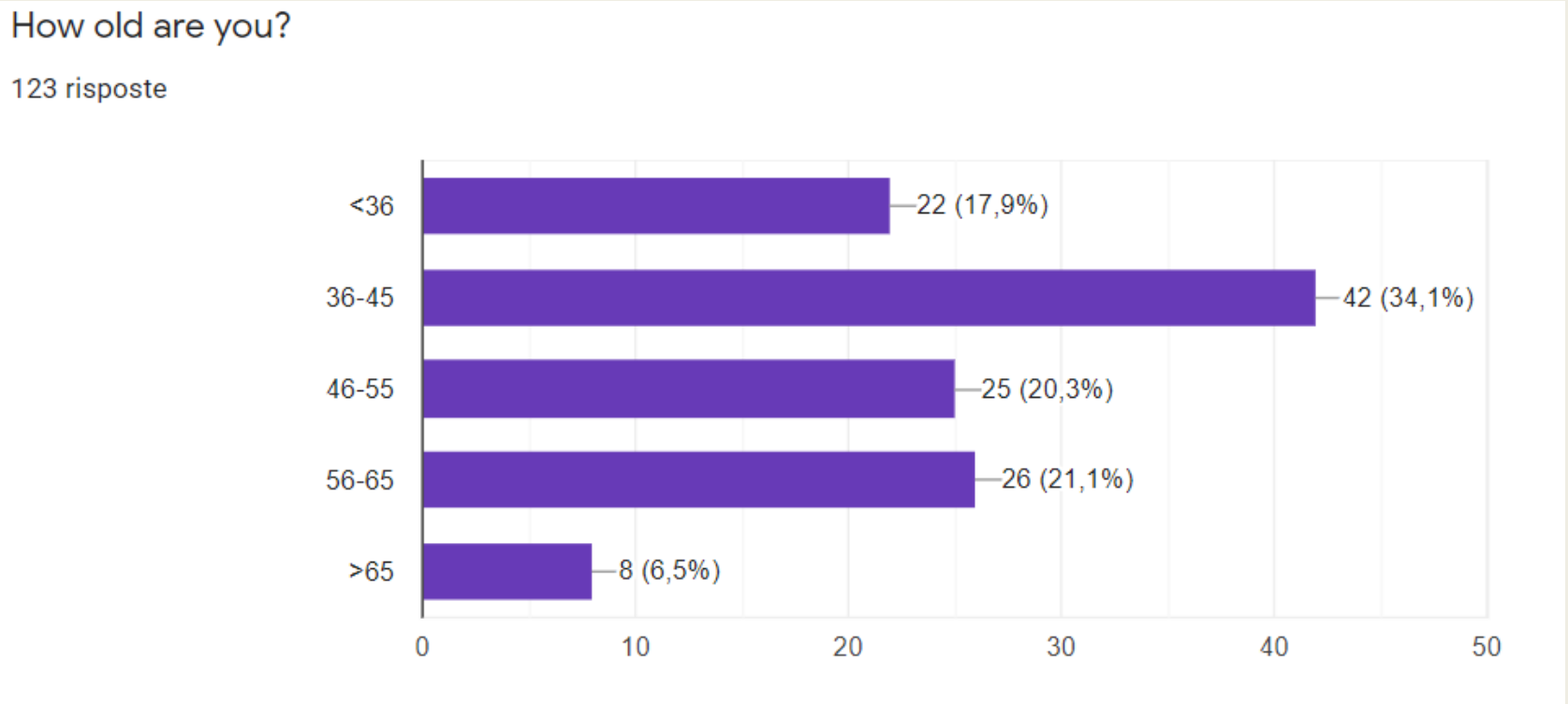
- 124 answers (today)



Survey not accessible from Cina?

Results: people

- Good age distribution

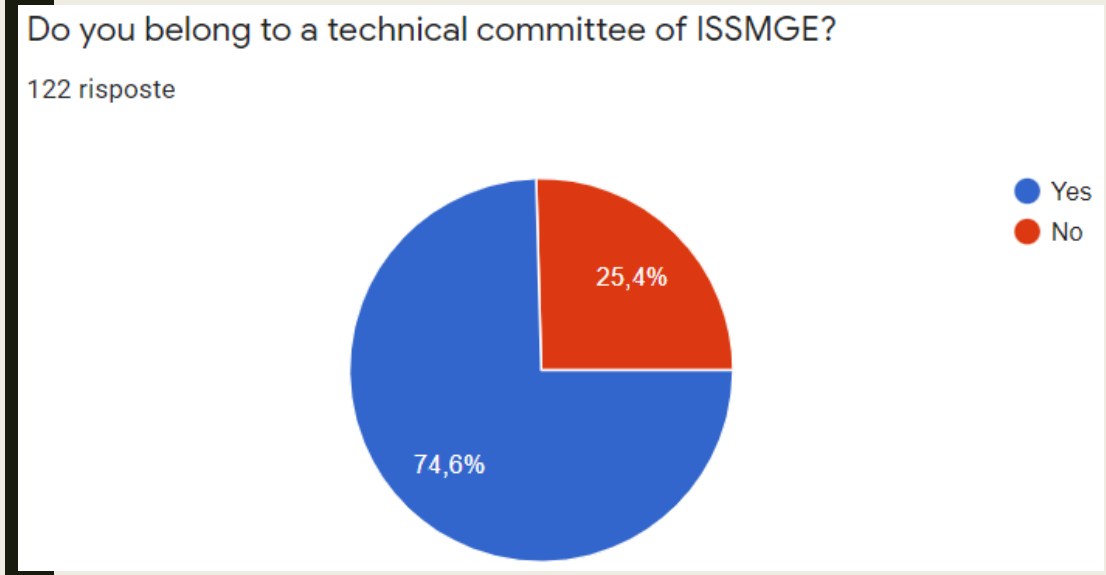


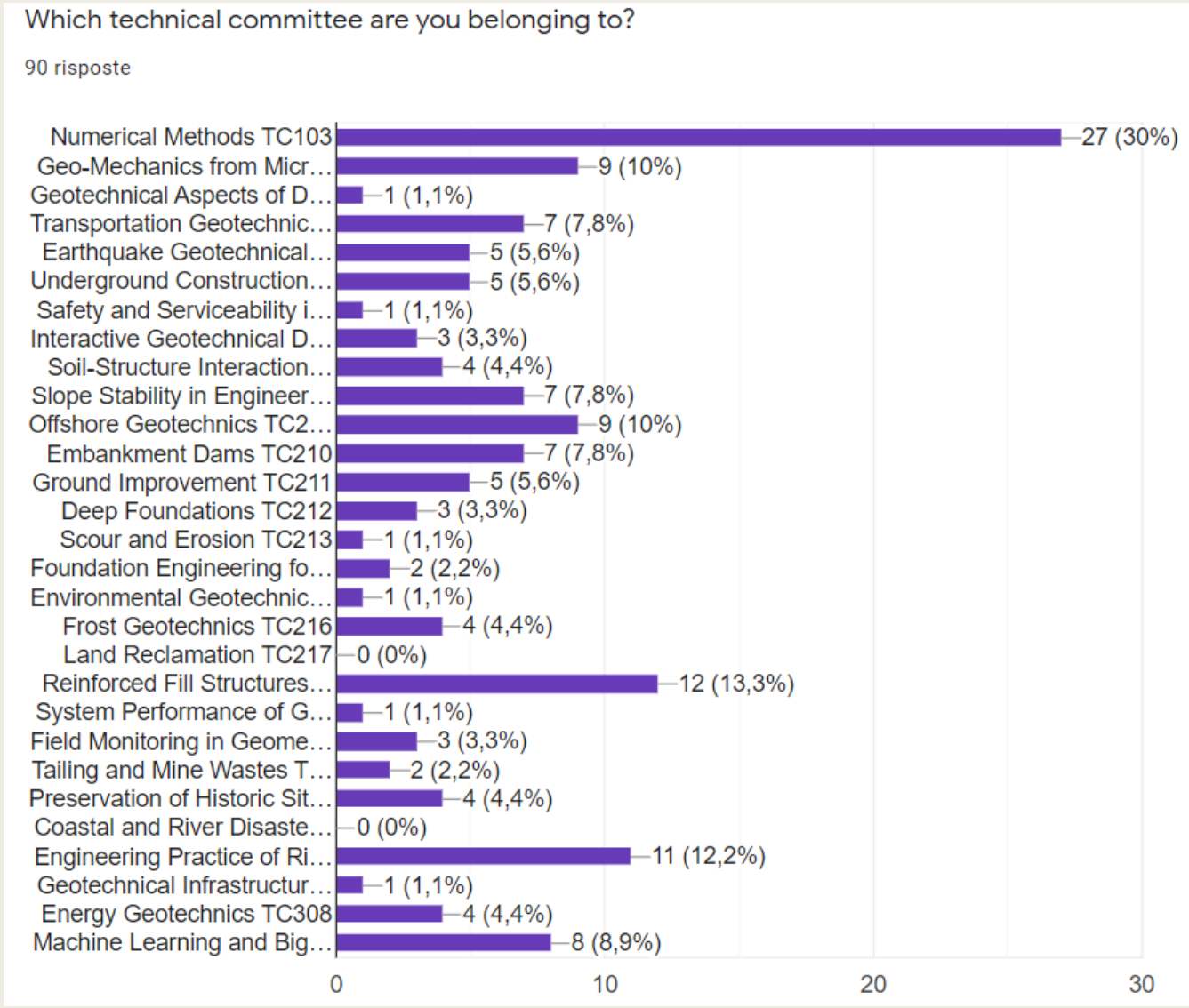
What is your main field of work/research?

What is your main field of work/research?

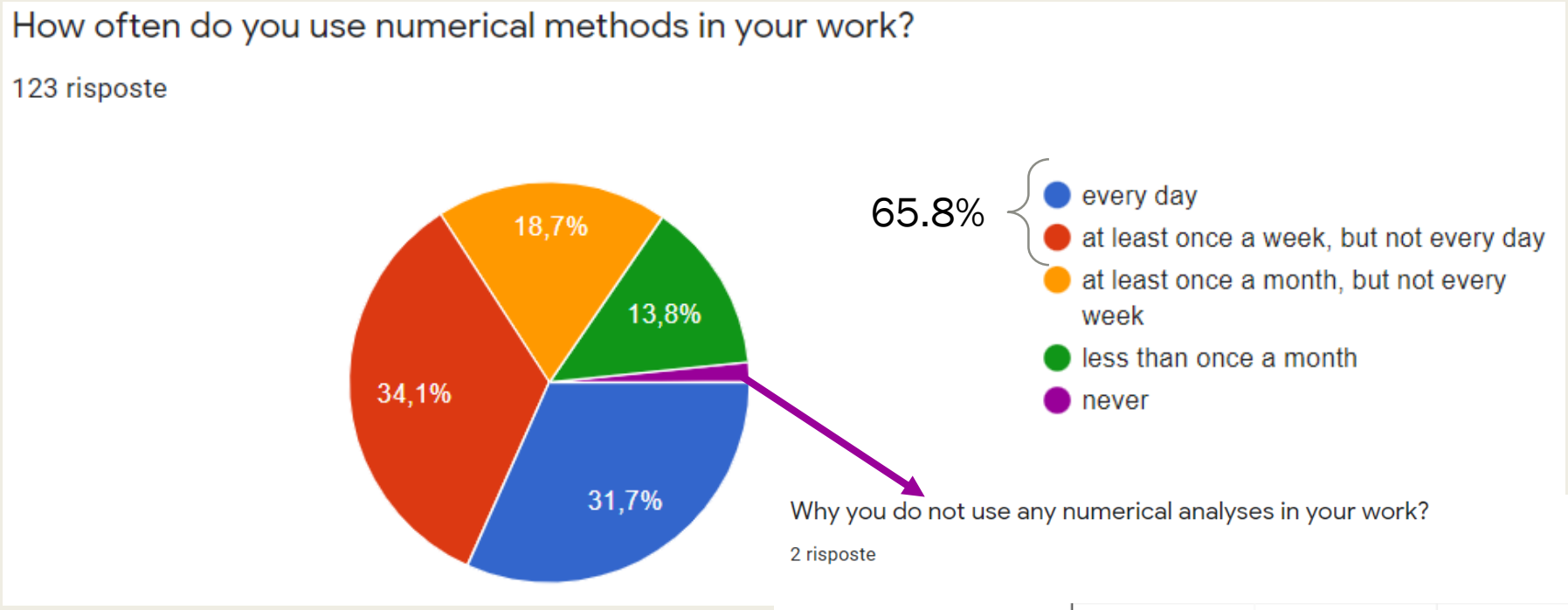
Results: technical committee

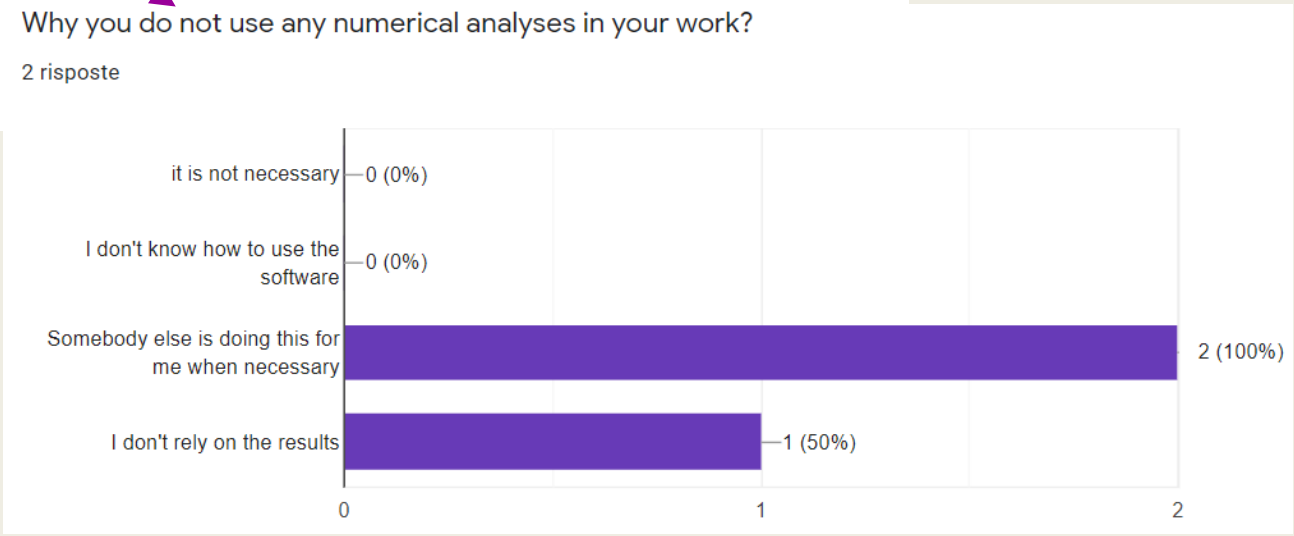
- Good participation





Use of numerical methods

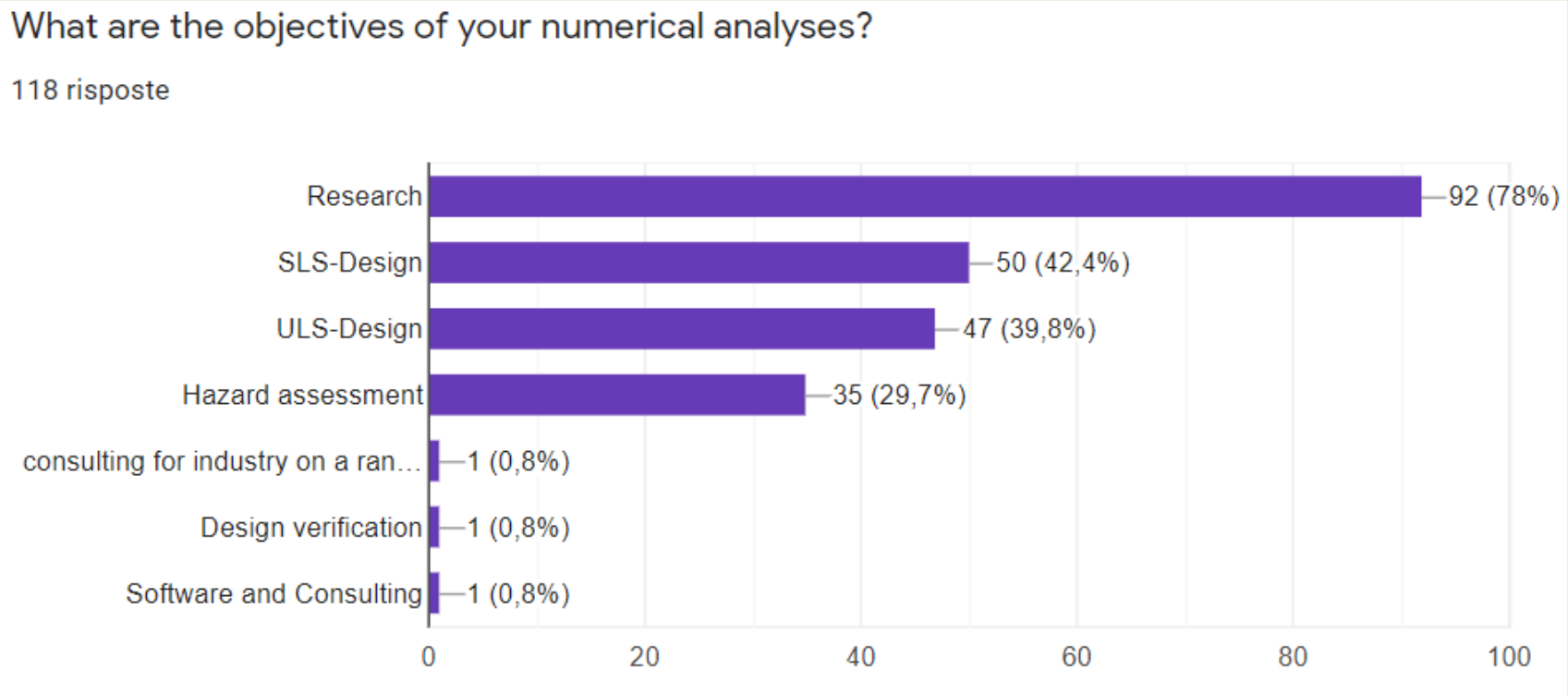




- The large majority uses numerical tools very often

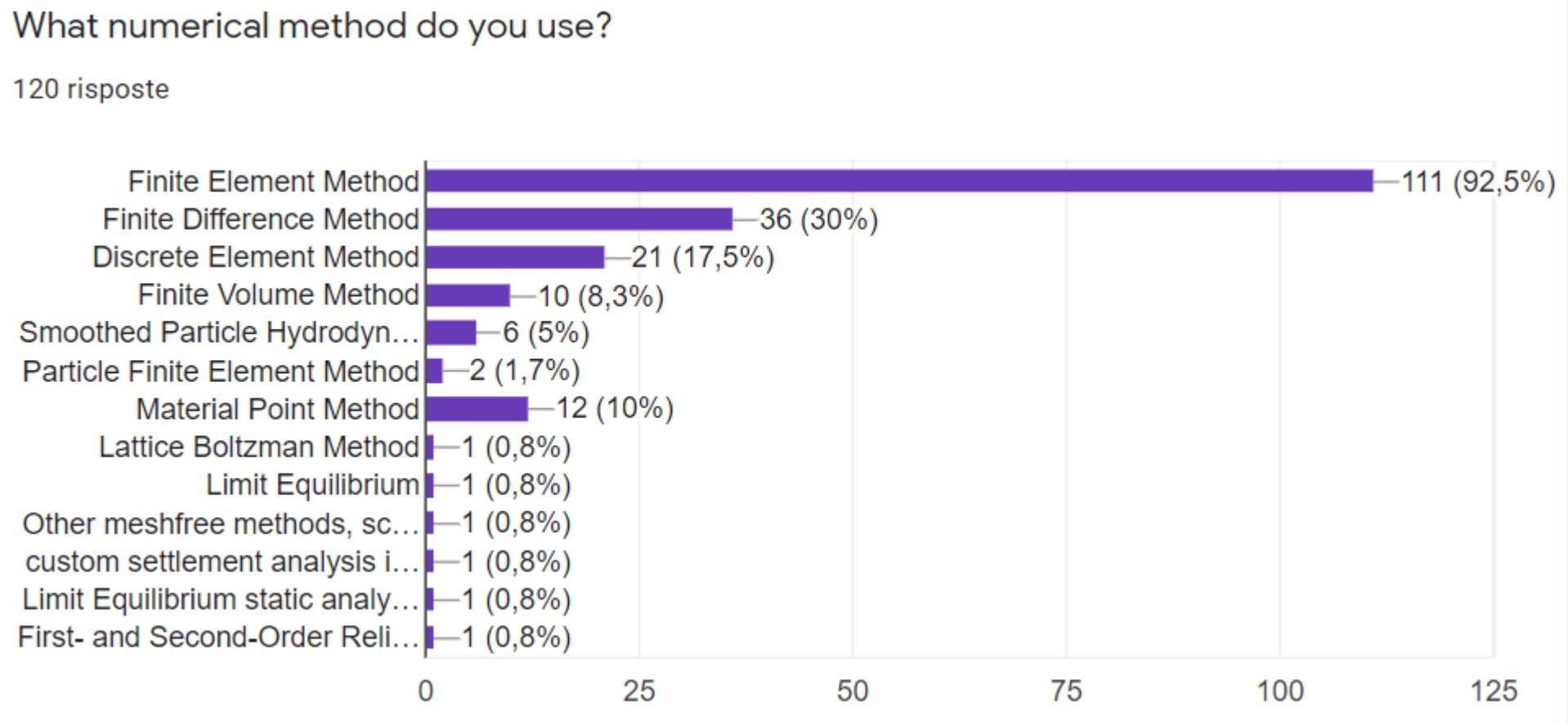
Use of numerical methods

- Numerical methods are used both for research and for practical applications

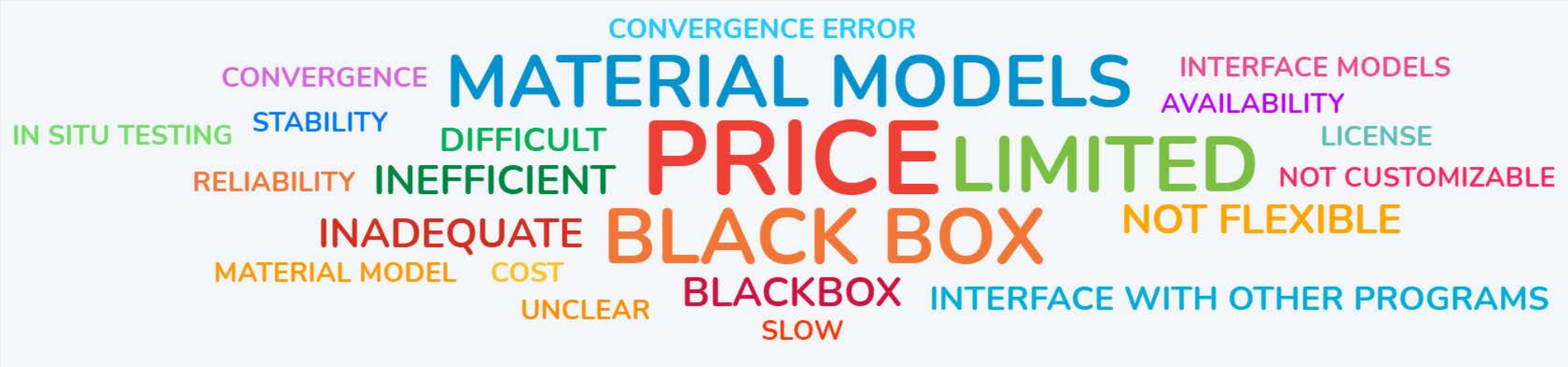


Use of numerical methods

- FEM and FDM are the most used, probably because of the software availability.
- DEM and MPM are also popular



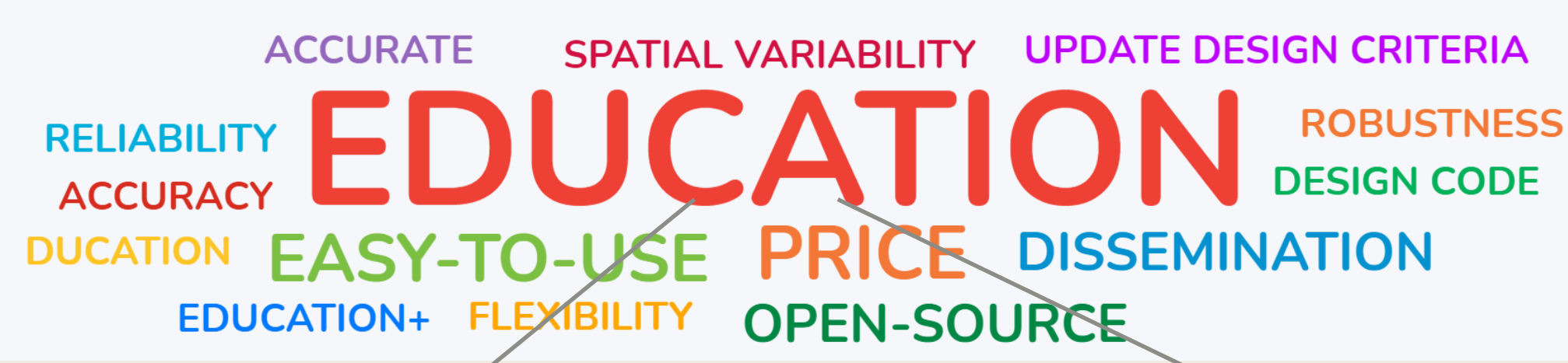
Main shortcomings of commercially available codes



THE FUTURE

Francesca Ceccato

What can be done to increase the use of numerical methods in practical geotechnical engineering?



- Education at university,
- training for practitioners,
- free and easily available tutorials,

- Learning the USE of the tool
- Understanding the method
- understanding of geotechnical problems, code output and software limitations

Collect suggestions for the future

Seems that education about numerical methods is a key issue

Set up collaboration with TC306: Education in geotechnical engineering