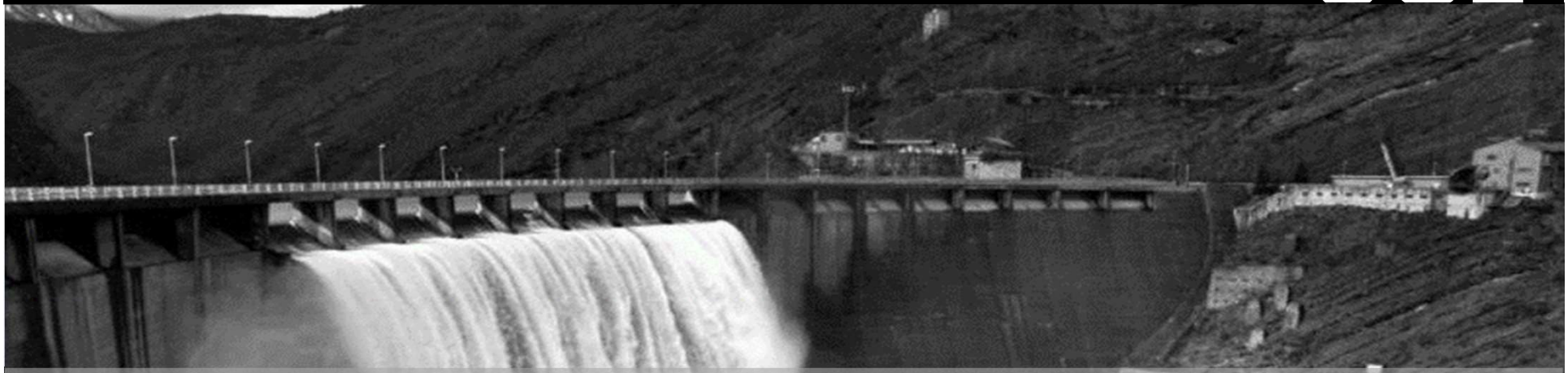
DEPARTMENT OF CIVIL, ENVIRONMENTAL & GEOMATIC ENGINEERING

UCL



Uncertainty Quantification and reduction in the structural analysis of existing concrete gravity dams

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Numerical analysis of dams

ICOLD-BW 9th-11th September 2019 MILANO

EPICentre

IN SUPREMÆ DIGNITATIS 1343

SC

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Outline

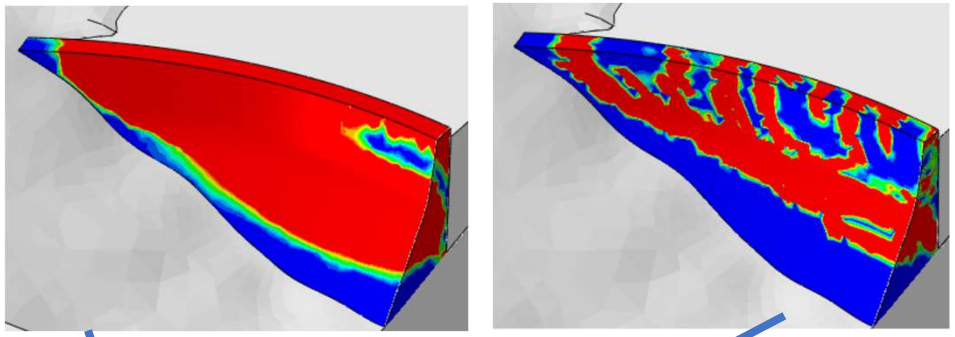
- Motivations and goals
- Main sources of uncertainties in the seismic analysis of concrete dams
- Uncertainty Quantification\Reduction: static behavior
- Uncertainty Quantification\Reduction: dynamic behavior
- Final remarks

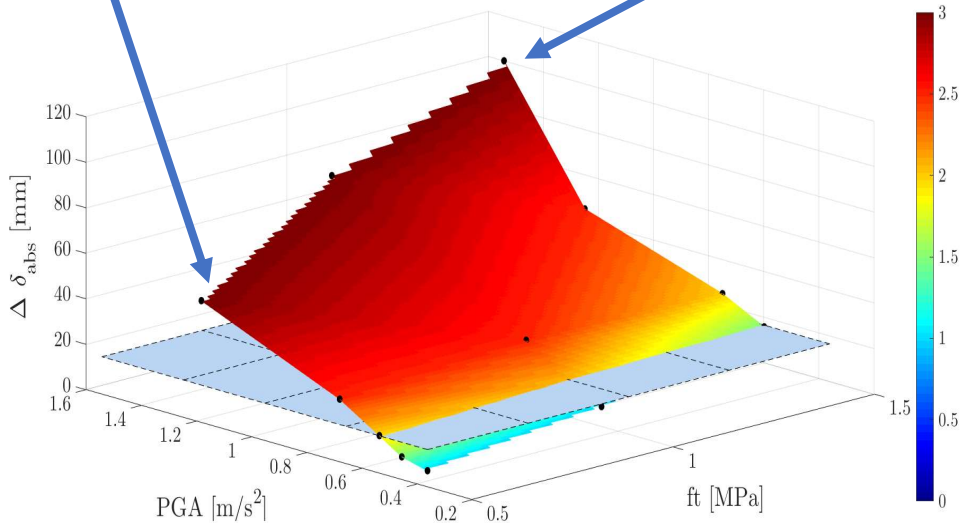
Motivations & goals

No case histories

Numerical models

Expert judgments





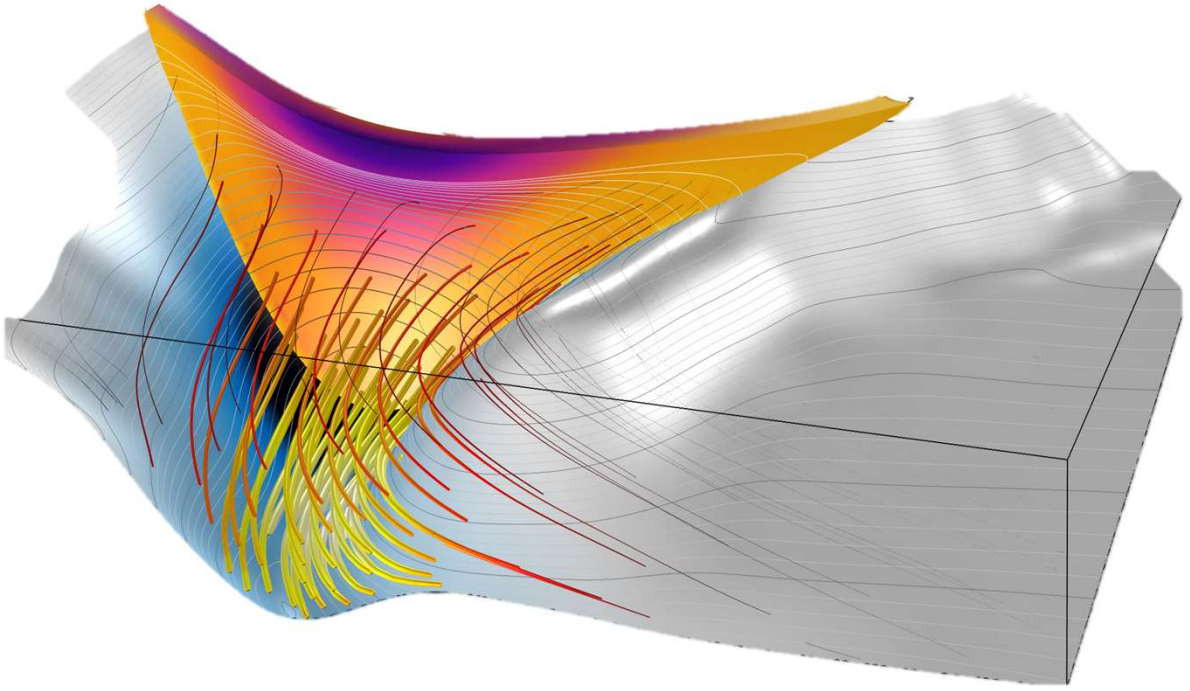
High level of uncertainty

- Inaccurate estimation of the structural seismic fragility
- Inaccurate prediction of the structural behavior for control purpose

Motivations & goals

Reduce the uncertainties involved in the twin-models of concrete gravity dams

- Improve the estimation of the structural fragility
- Improve the structural control



Main sources of uncertainties

Model class definition

- Geometry (2D or 3D model)
- Soil-Structure Interaction (SSI) model
- Fluid-Structure Interaction (FSI) model
- Material constitutive models

Epistemic uncertainties

- Model parameters

Bayesian Framework

$$\ln\left(\hat{\delta}_i^{gPCE}\left(\mathbf{x},\boldsymbol{\theta}_{\mathrm{gPCE}}\right)+\hat{\delta}_i^{FA}\left(\boldsymbol{\theta}_{\mathrm{FA}}\right)+\hat{\delta}_i^{K}\left(\theta_{\mathrm{K}}\right)+l\right)+\gamma\left(\mathbf{x},\boldsymbol{\theta}_{\gamma}\right)+\sigma\epsilon$$

Bayes' formula

$$p\left(\mathbf{x},\boldsymbol{\Theta},\boldsymbol{\Xi}|\mathbf{y}\right)=\kappa L\left(\mathbf{x},\boldsymbol{\Theta},\boldsymbol{\Xi}|\mathbf{y}\right)p\left(\boldsymbol{\Theta}|\boldsymbol{\Xi}\right)p\left(\boldsymbol{\Xi}\right)$$

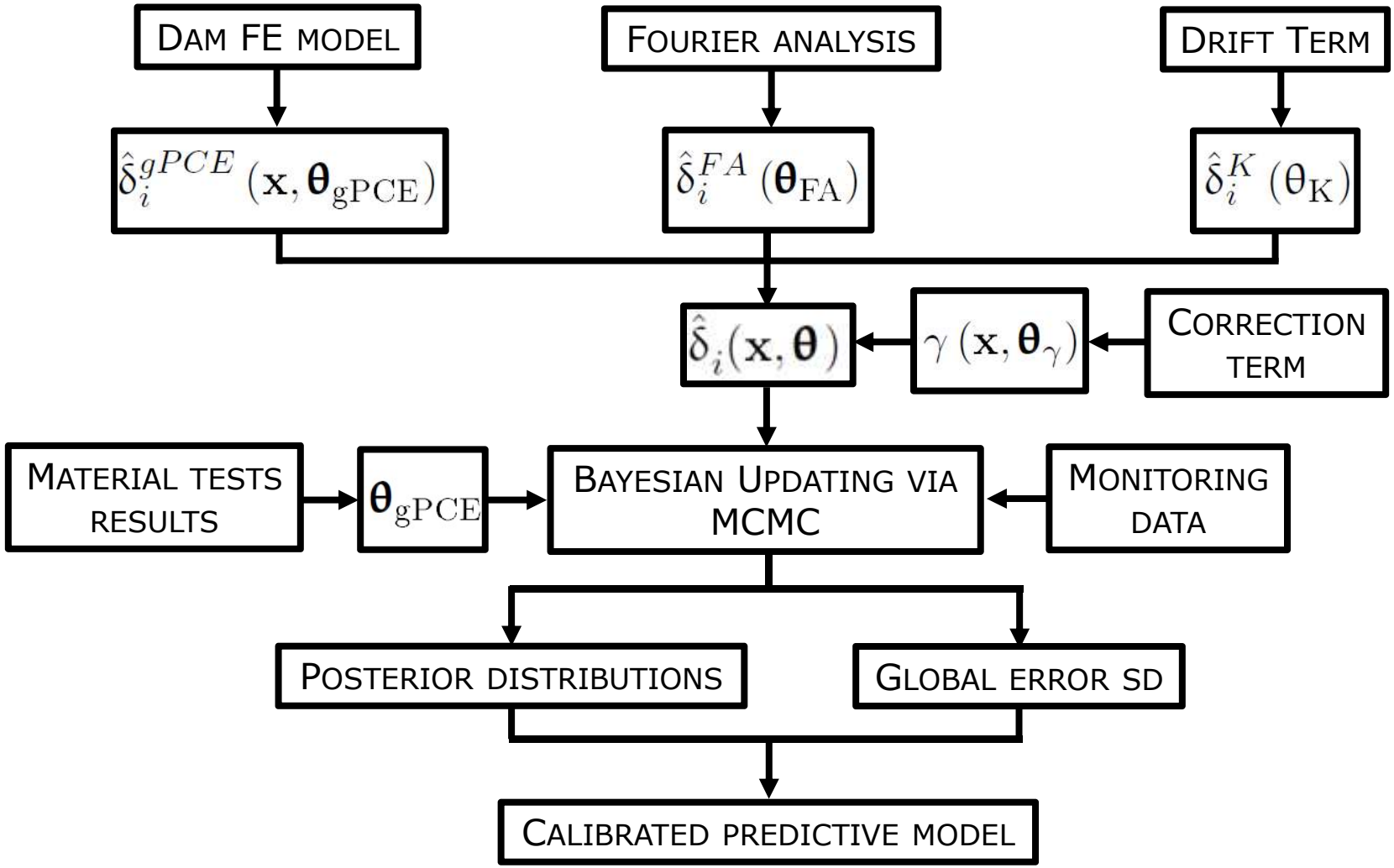
Likelihood function

$$L\left(\mathbf{x},\boldsymbol{\theta}_{\mathrm{m}},\Sigma\ ,\Xi\right)\propto\prod_{i=1}^{n}\frac{\exp\left[-\frac{1}{2}\mathbf{r}_i{}^{T}\left(\mathbf{x},\boldsymbol{\theta}_{\mathrm{m}},\boldsymbol{\Xi}\right)\boldsymbol{\Sigma}^{-1}\mathbf{r}_i\left(\mathbf{x},\boldsymbol{\theta}_{\mathrm{m}},\boldsymbol{\Xi}\right)\right]}{\sqrt{|2\pi\boldsymbol{\Sigma}\ |}}$$

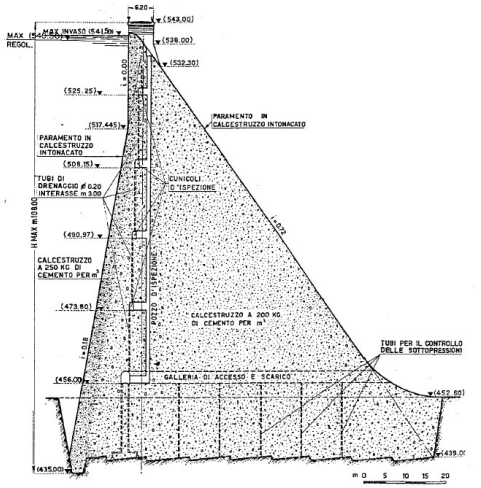
- $\mathbf{x}$ Measurable variables
- $\boldsymbol{\theta}_{\mathrm{m}}$ Model parameters vector
- Σ Covariance matrix of the error terms
- Ξ Hyper-parameters vector

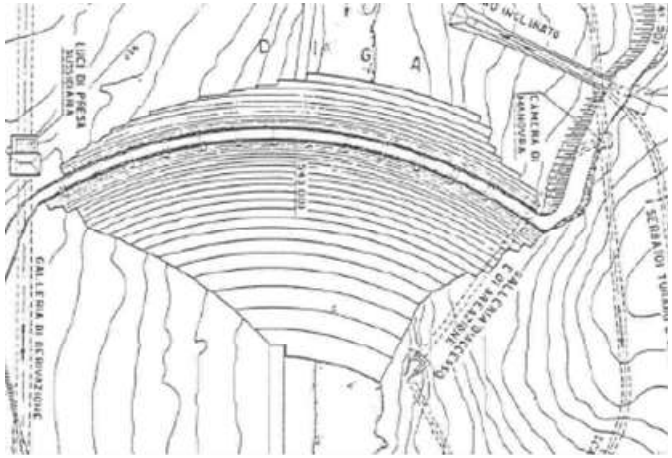
Sevieri, G. et al. (2019). *Concrete gravity dams model parameters updating using static measurements*. Eng. Str., 196.

Bayesian Framework



Static Case of study: Numerical model

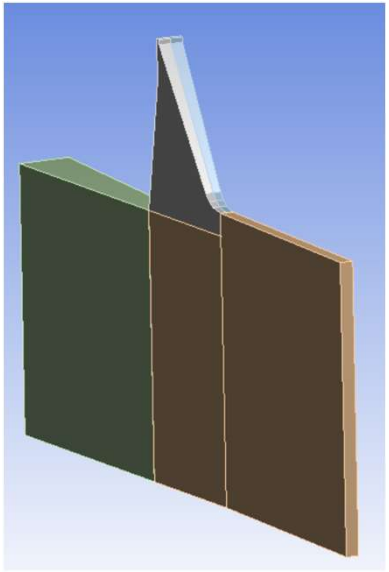




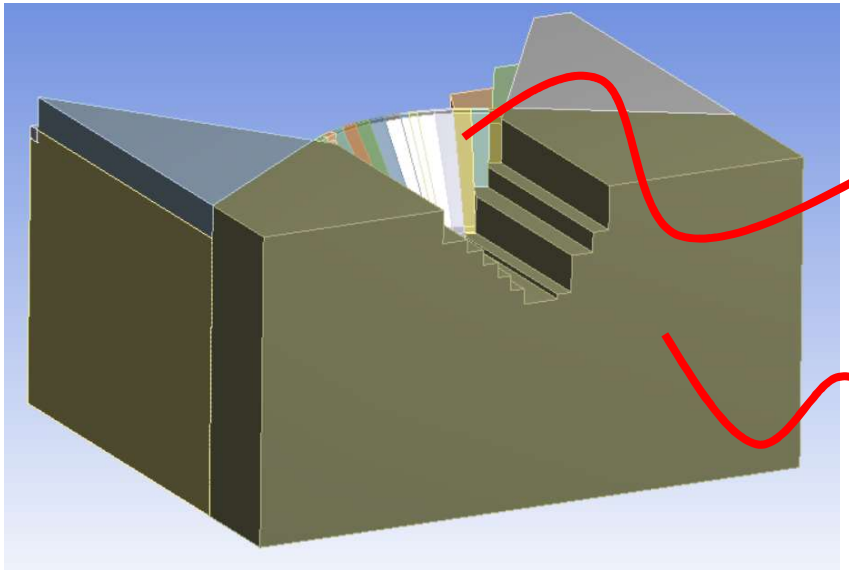
Important characteristics:

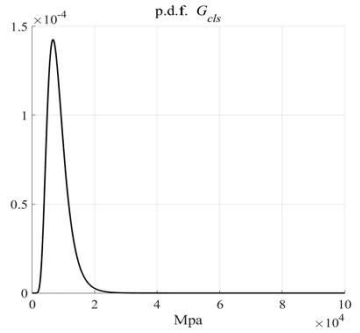
- 11 monoliths
- total crest length 234 m
- maximum height: 108 m

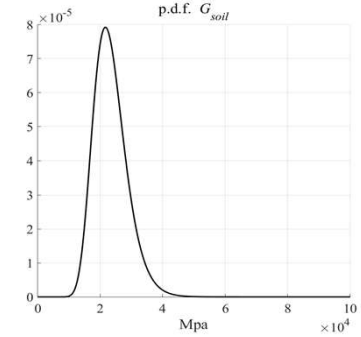
Single Monolith Model



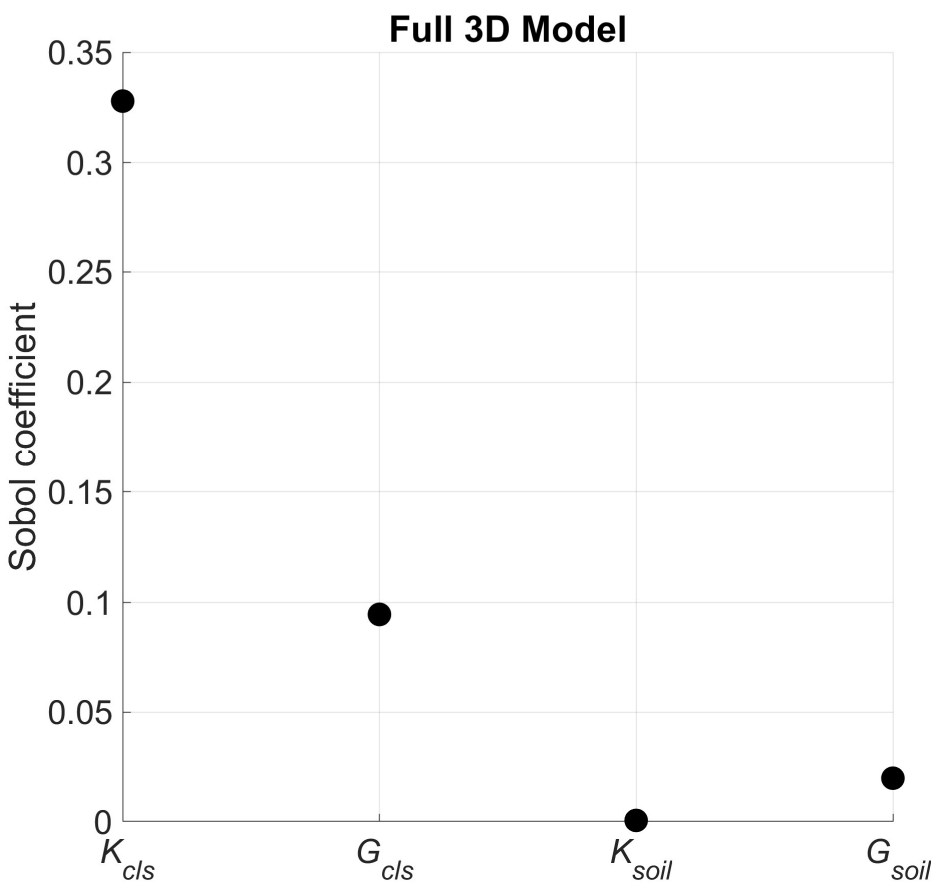
Full Model

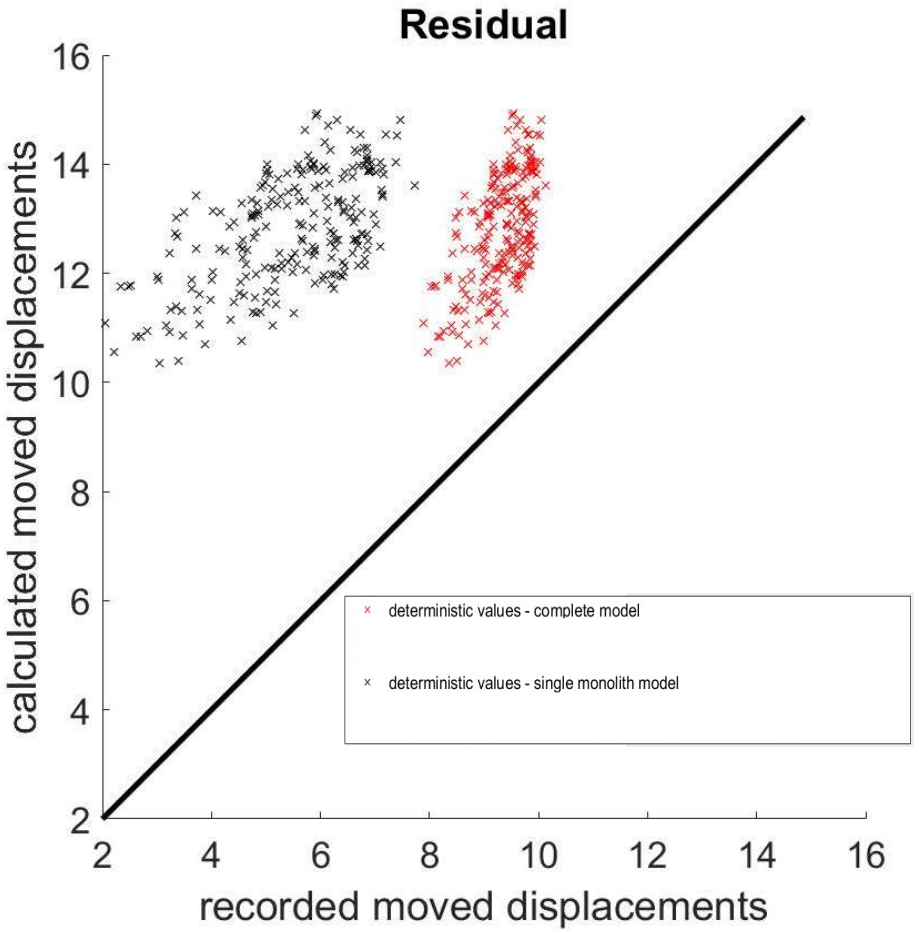




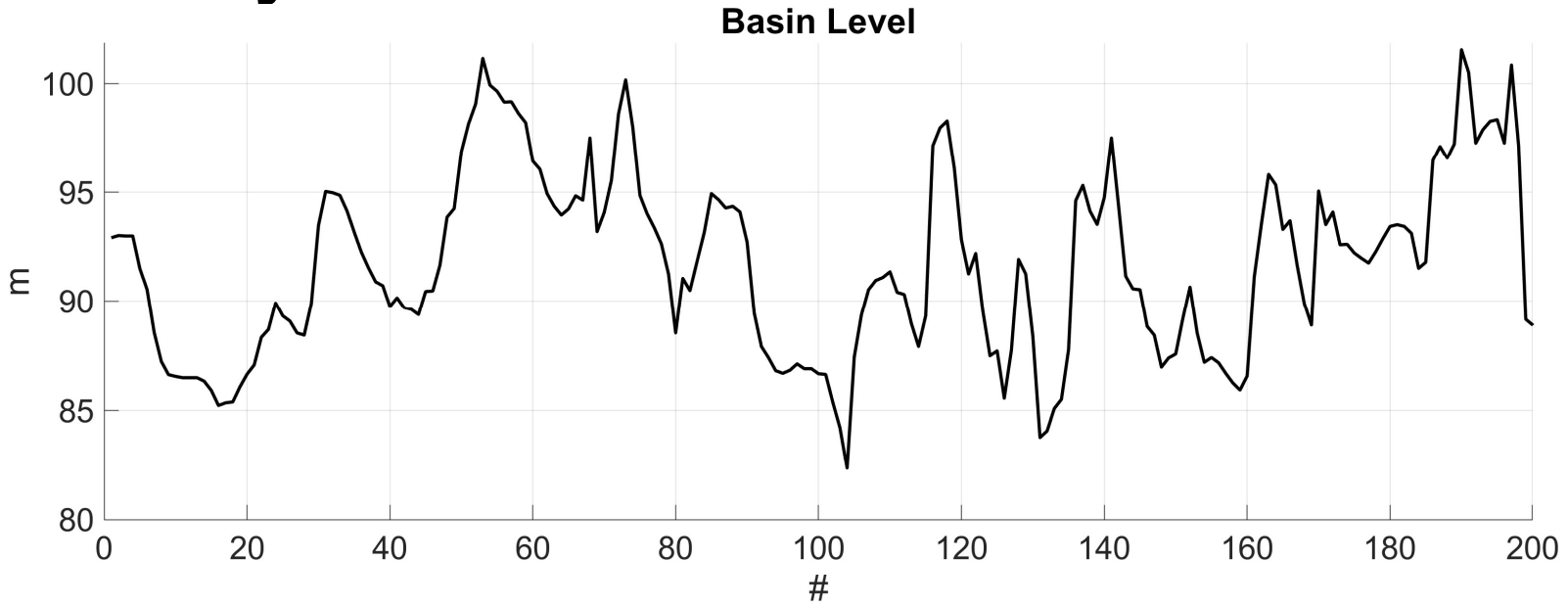


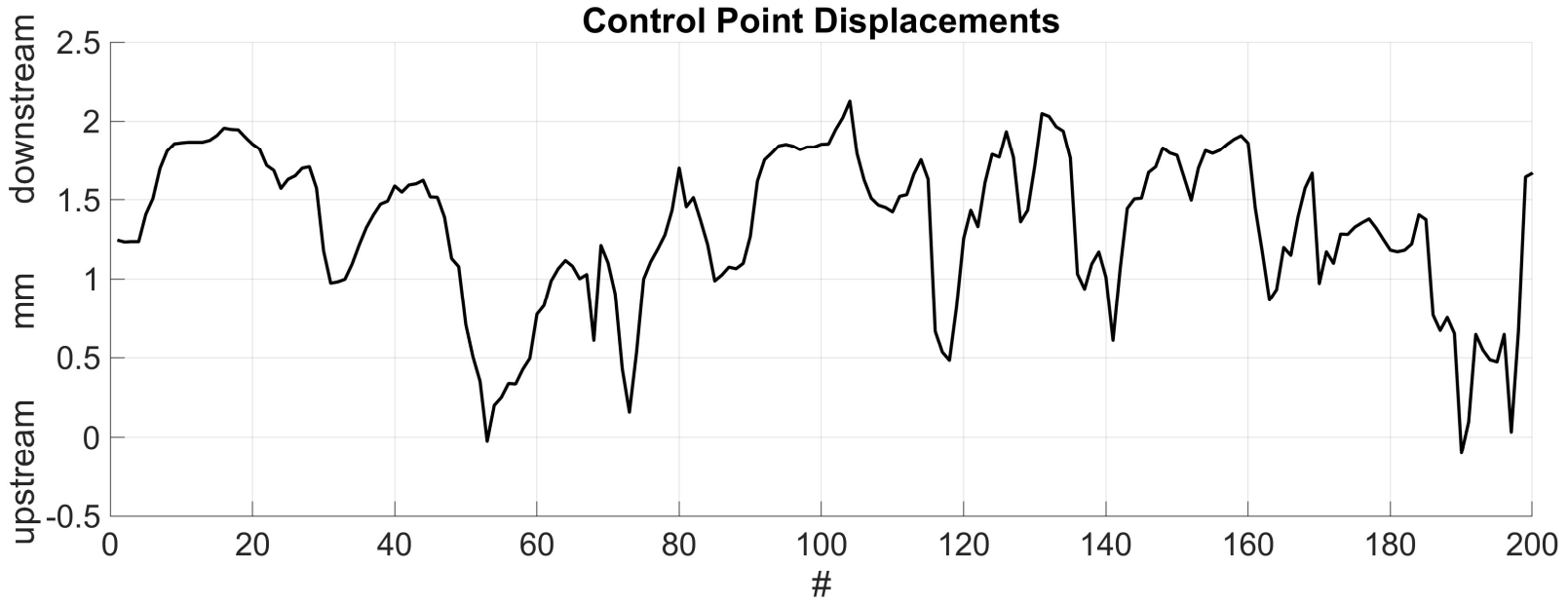
Uncertainty Quantification: Static behavior



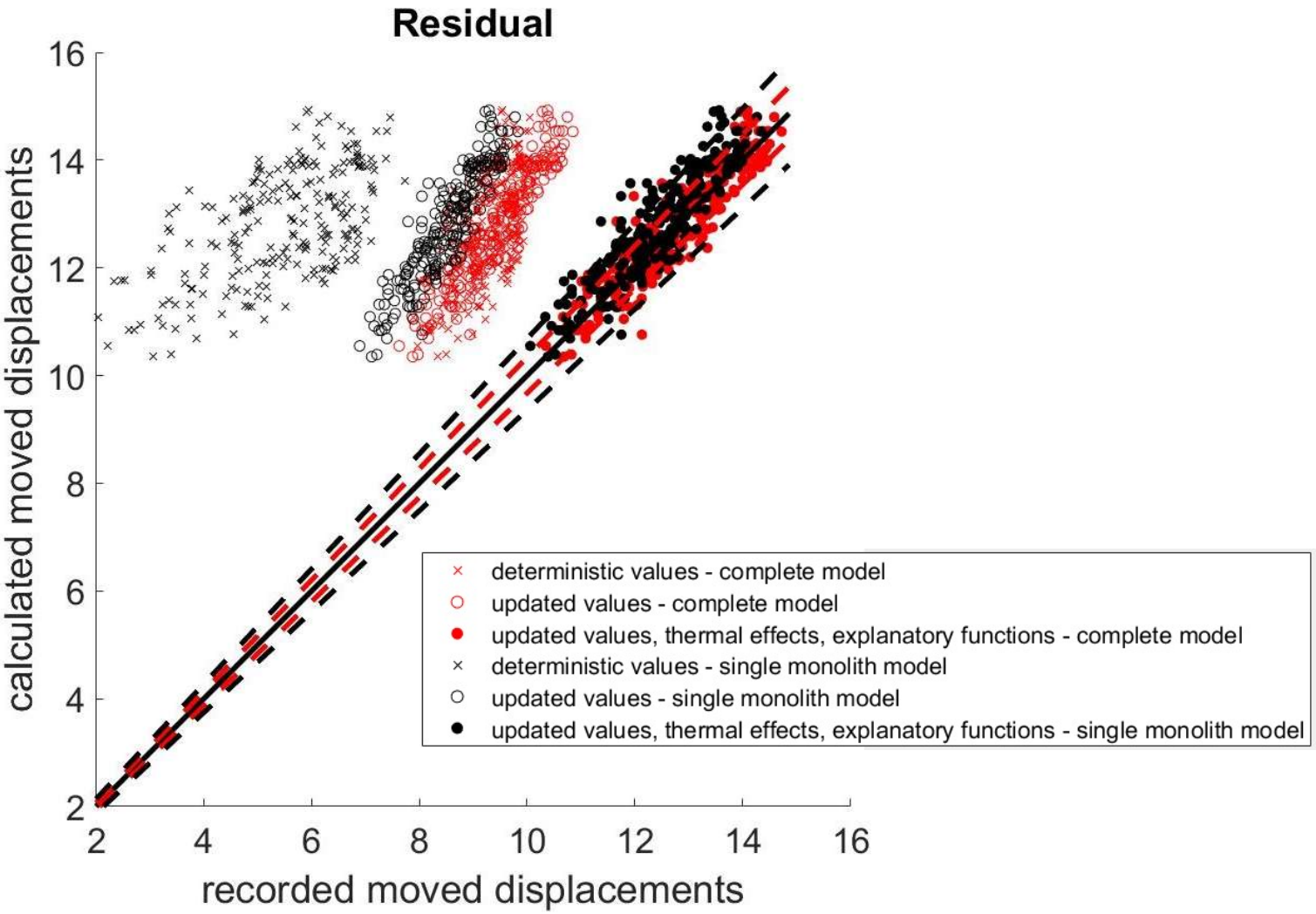


Uncertainty Reduction: Static measurements



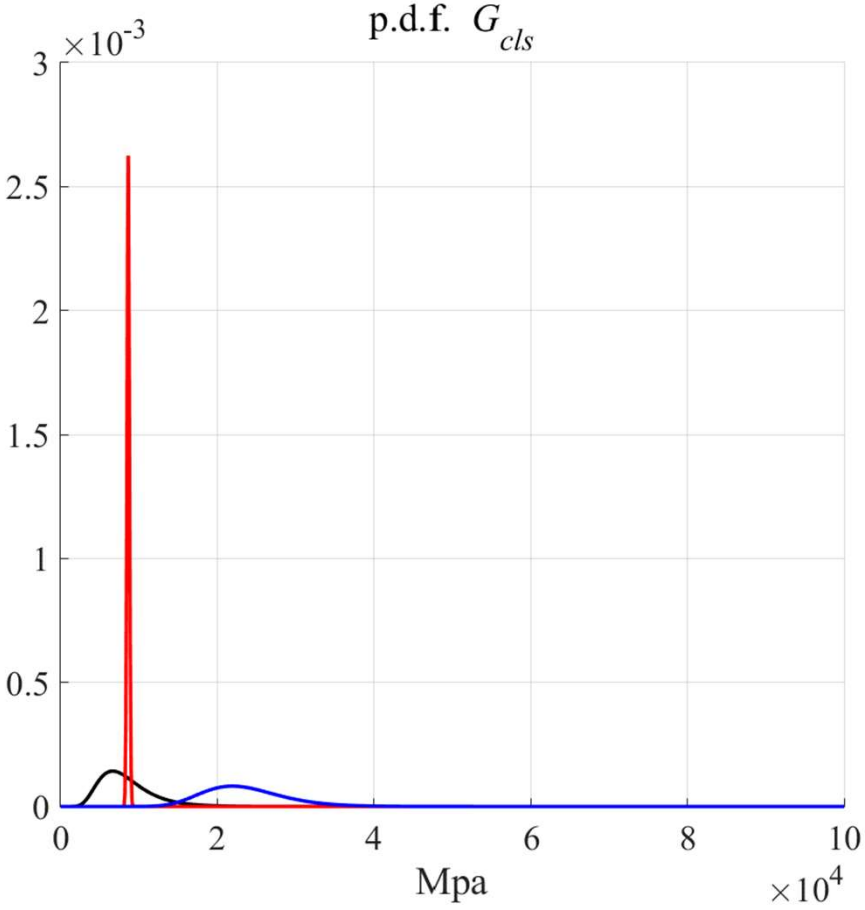


Uncertainty Reduction: Static behavior



Uncertainty Reduction: Static behavior

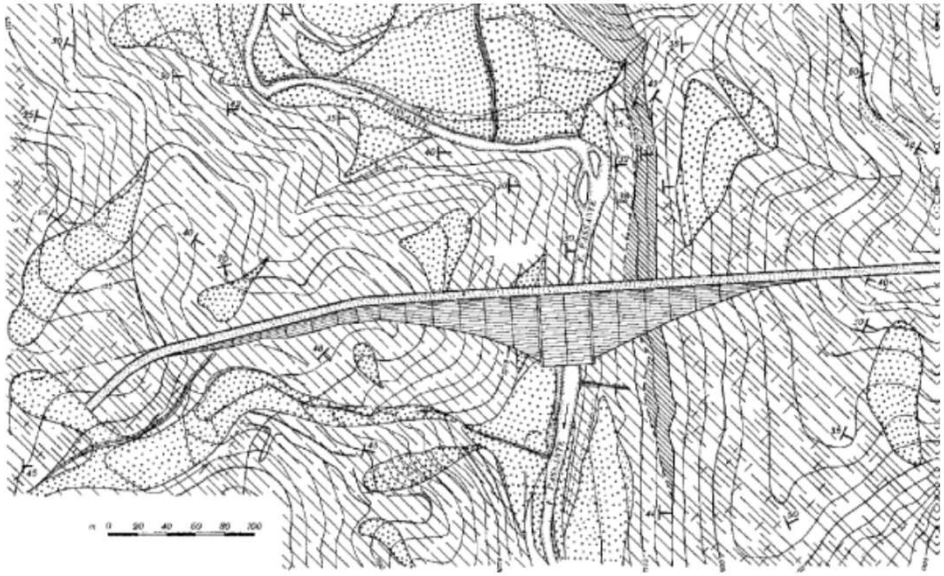
Concrete shear modulus

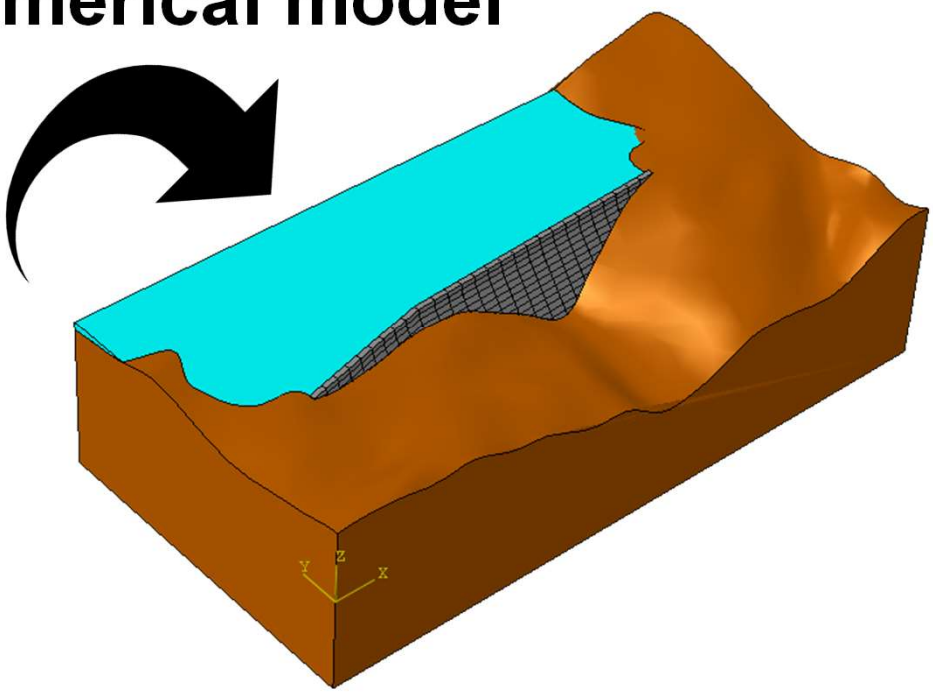


- The use of the **single monolith model** leads to an overestimation of the mean values of the material mechanical parameters. This is due to the lack of stiffness related to the absence of other monoliths. The **high values** which characterize the **standard deviations** express the uncertainty in the use of this modelling approach.

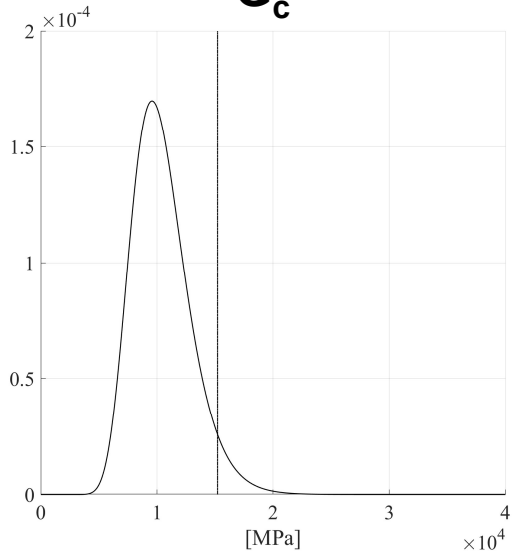
- The use of the **full model** leads to plausible mean values of the mechanical parameters.

Dynamic Case of study: Numerical model





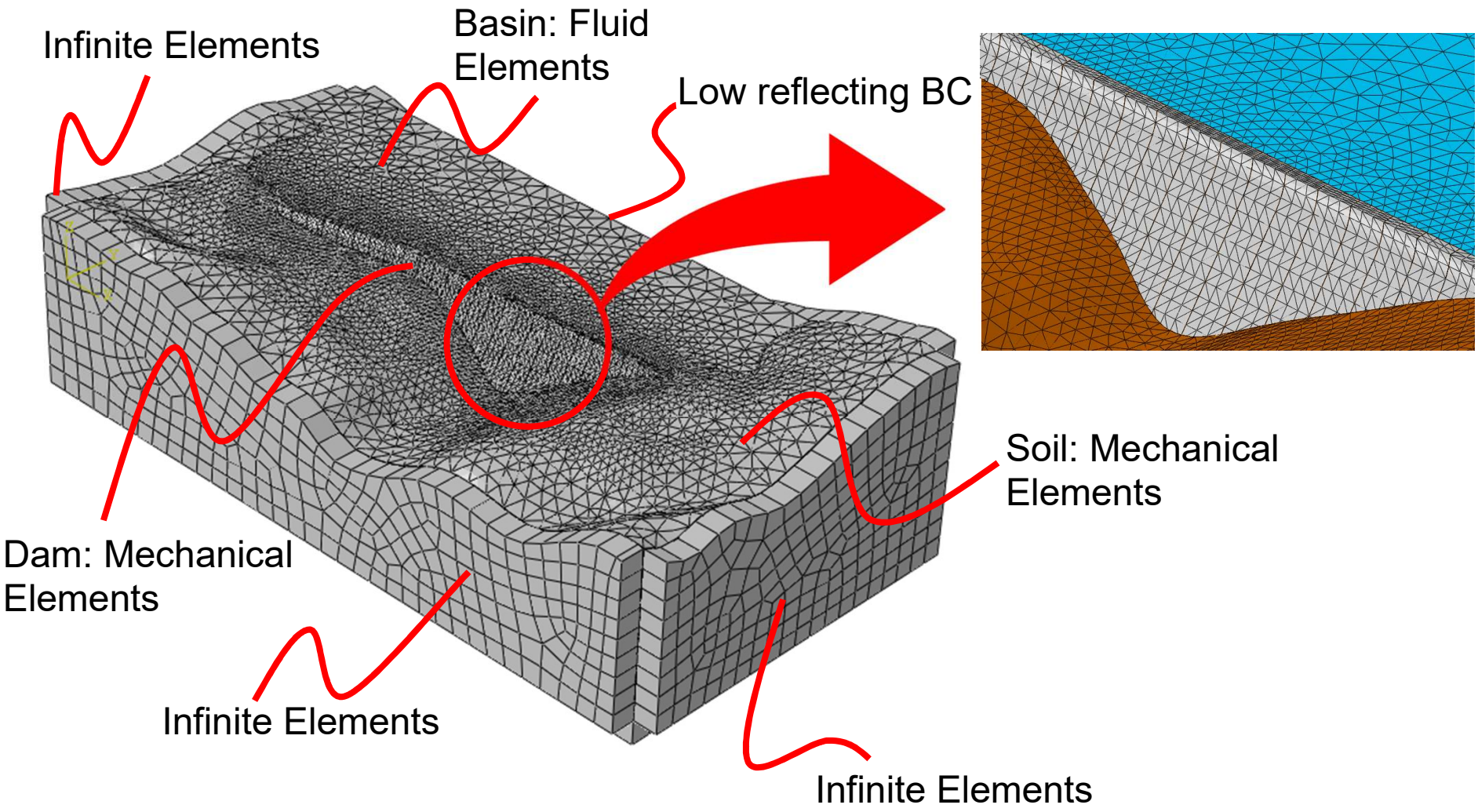
G_c



Important characteristics:

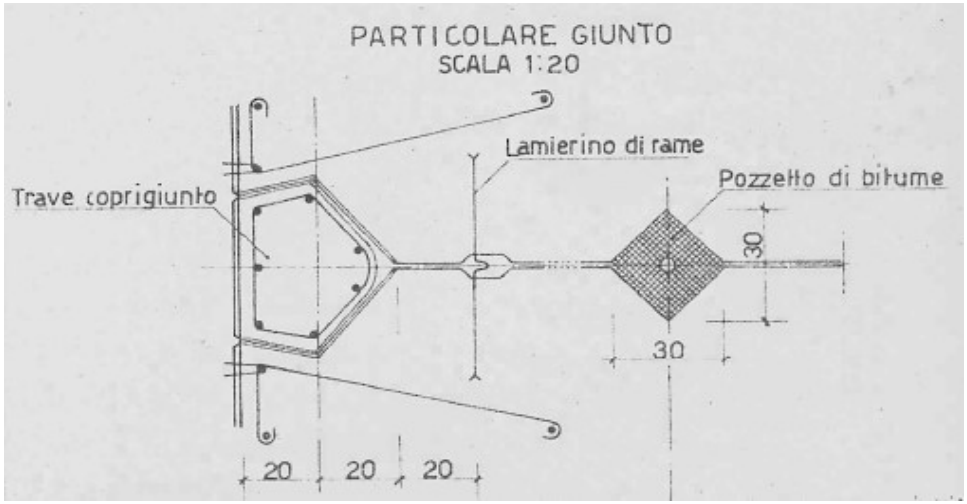
- 26 monoliths
- total crest length 450 m
- maximum height: 65 m

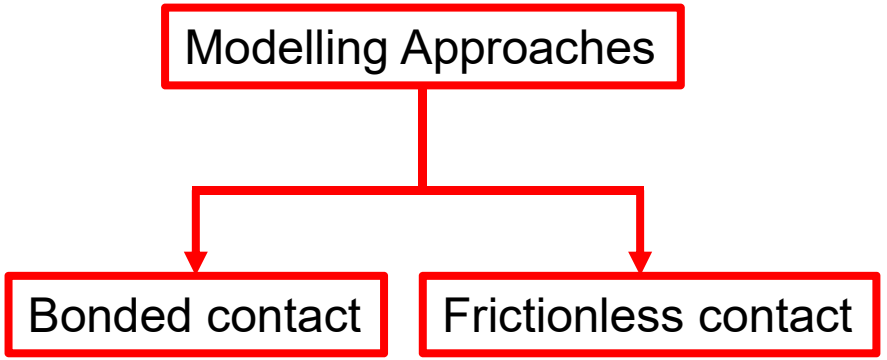
Dynamic Case of study: Numerical model



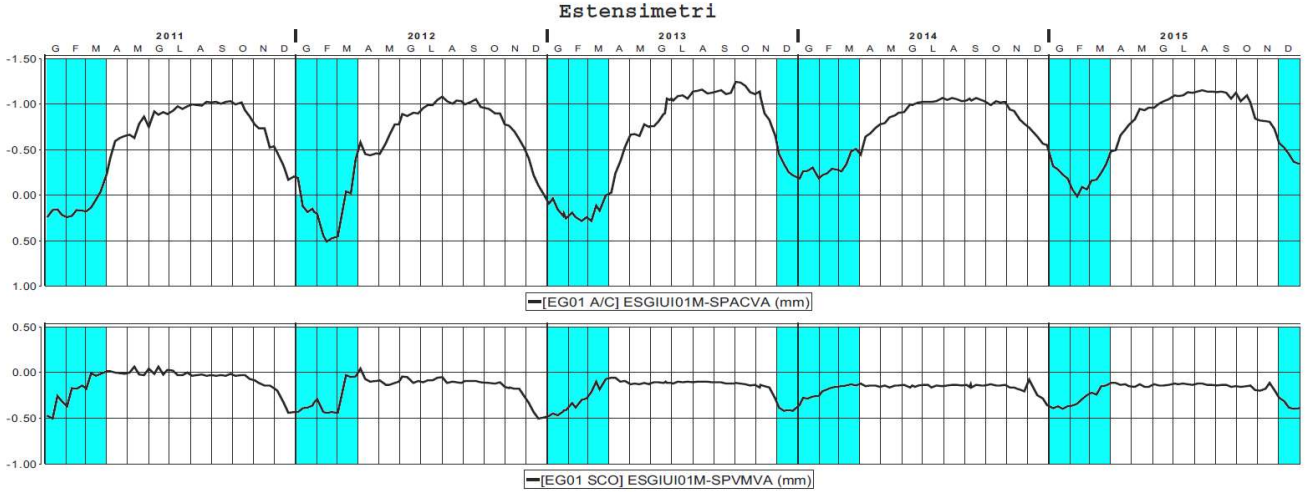
Case of study: vertical contraction joint modelling

Vertical contraction joint typology





Vertical contraction joint behavior

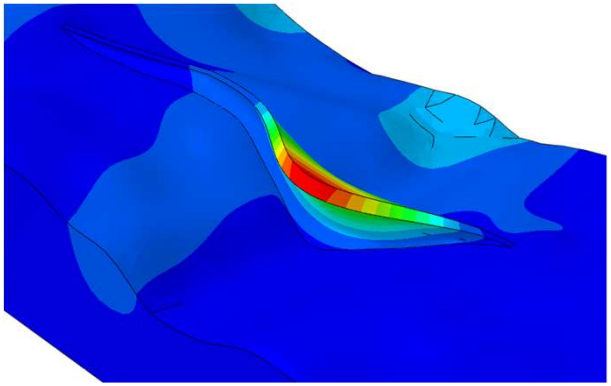
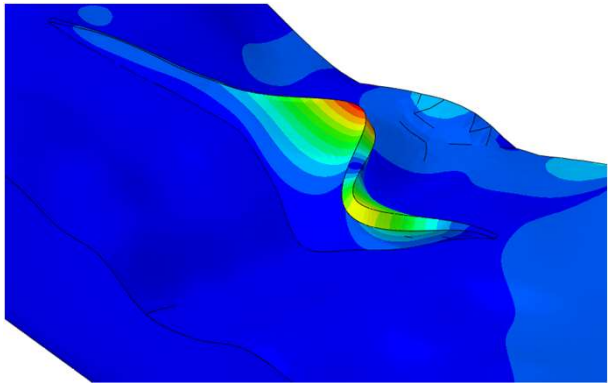
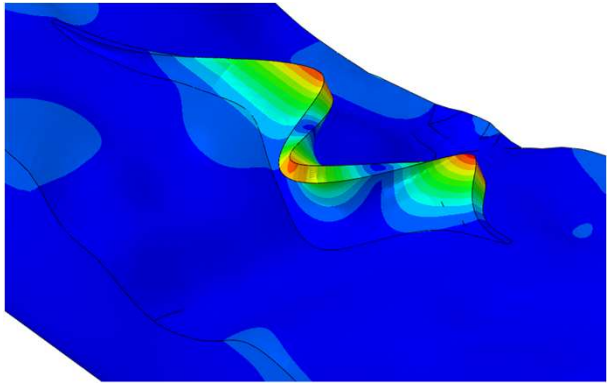


U-D direction

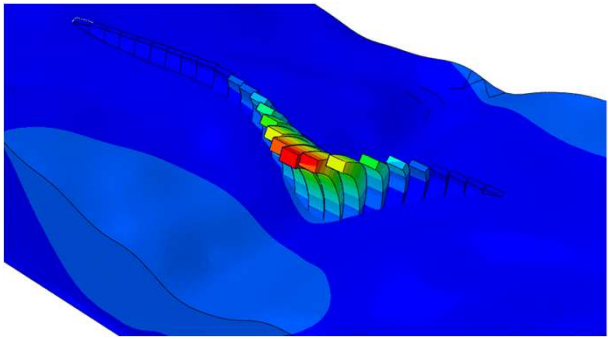
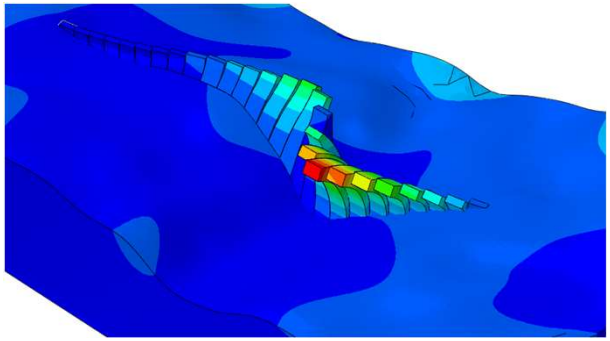
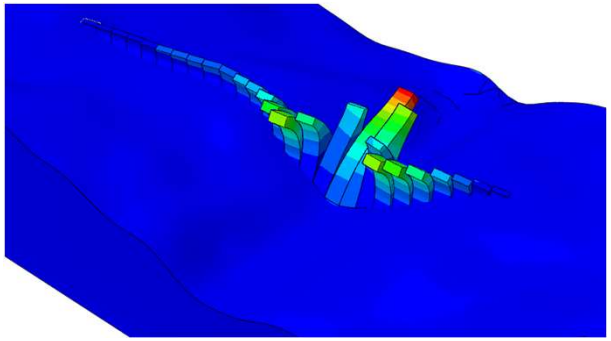
Cross-valley direction

Uncertainty Quantification: Dynamic behavior

Bonded model

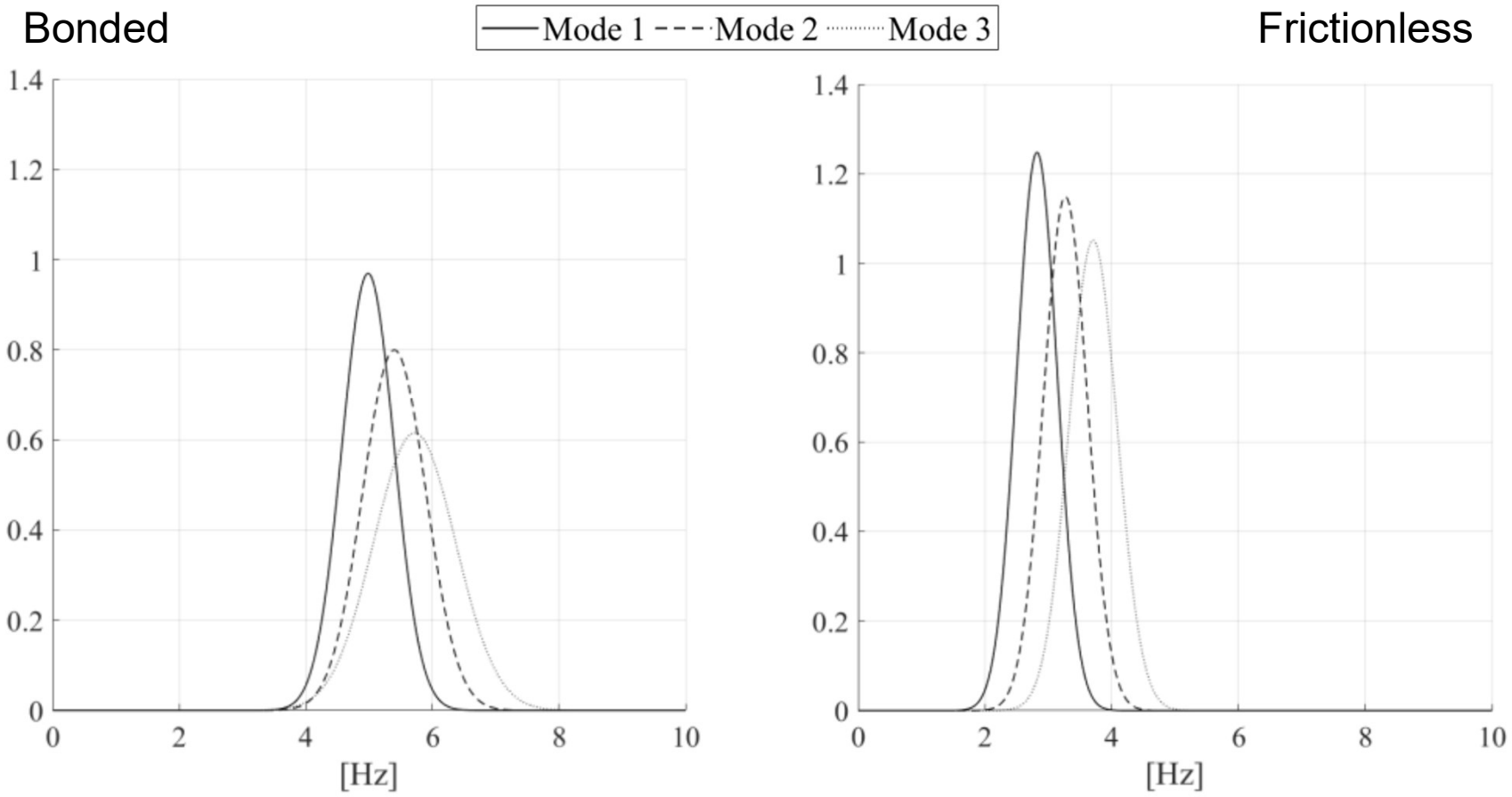




Frictionless model

Uncertainty Quantification: Dynamic behavior

Frequency variation

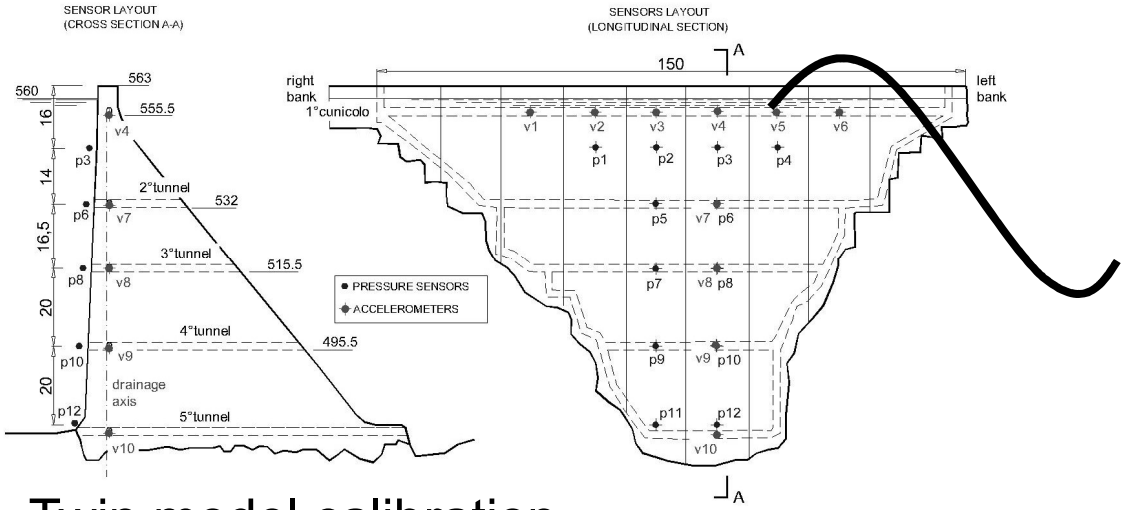


The lack of stiffness of the "**frictionless**" model leads to **smaller frequencies values**.

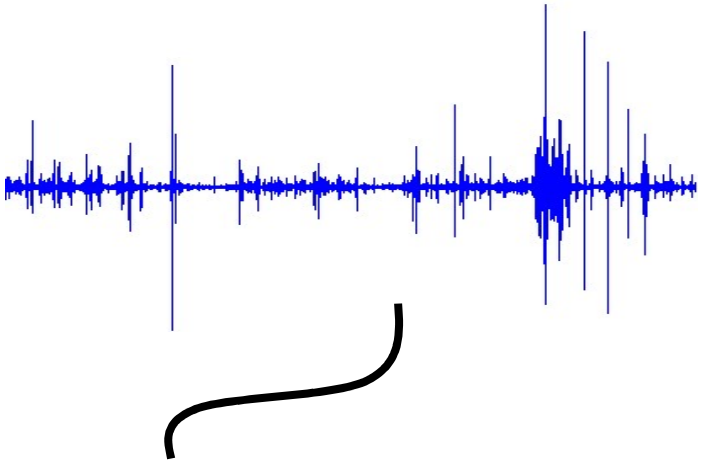
In both cases **standard deviations increase toward higher frequency**.

Uncertainty Reduction: Dynamic measurements

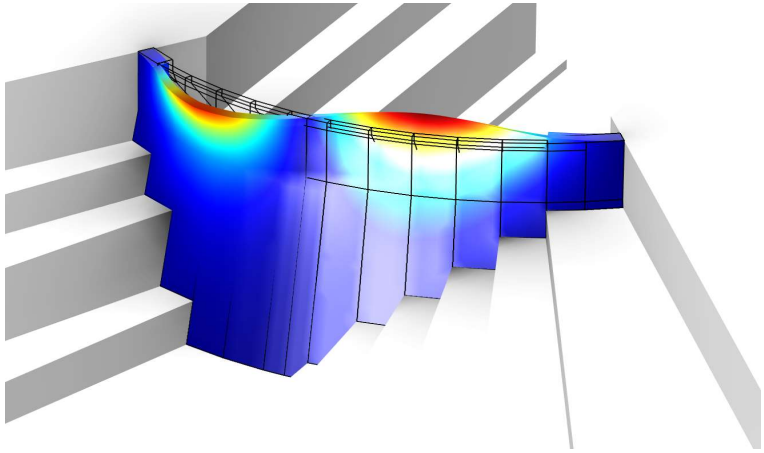
Dynamic monitoring system



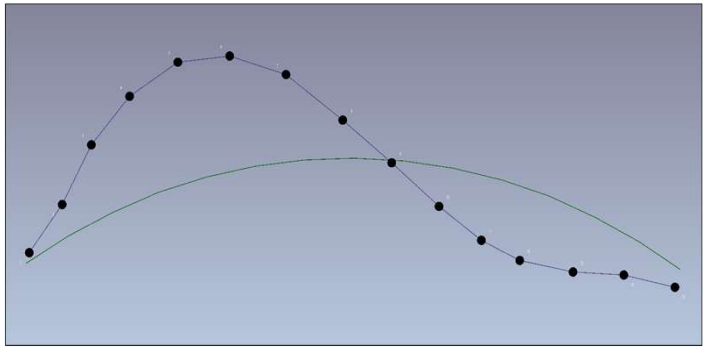
Ambient vibration



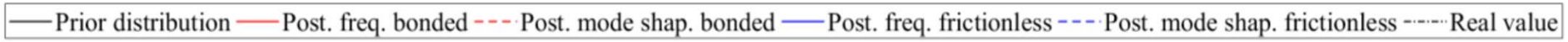
Twin model calibration



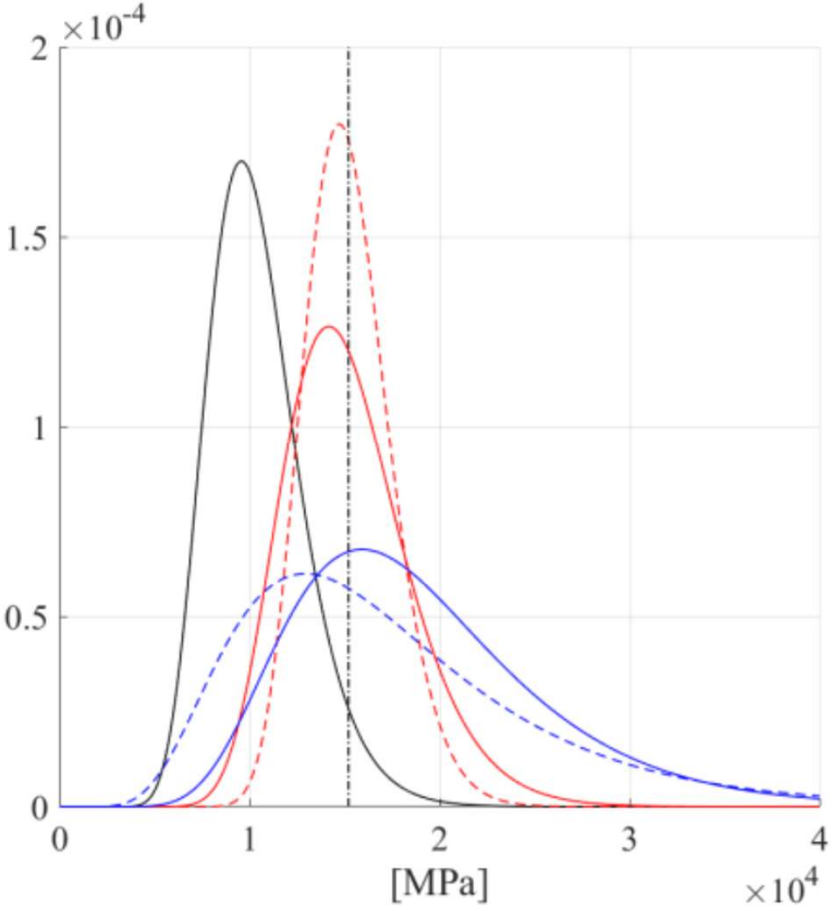
Operational Modal Analysis



Uncertainty Reduction: Dynamic behavior



Concrete shear modulus



"Experimental" modal characteristics simulated through a **high-fidelity model**, assuming a **bonded** behavior for the vertical contraction joints.

- The **bonded** predictive models allows determining the **correct values** of the material parameters.

- The **frictionless** predictive models lead to an **overestimation** of the material parameters, this is due to the lack of stiffness related to the absence of the interaction between monoliths.

Final Remarks

● Hybrid gPCE-based predictive models allow performing the **real-time dam control without HPC**.

● The **Bayesian inference** is a powerful tool for **the reduction of the effect of epistemic uncertainties**. Its probabilistic nature allow improving both the fragility derivation and the structural control.

● The vertical contraction joint behavior strongly affects static/dynamic analysis results. **This aspect cannot be neglected** in the prediction of the dam behavior.

Ongoing works

● Reduction of the effect of **material strength parameter** uncertainties.

● Definition of **high-fidelity hybrid-predictive models for real-time dam control (**without HPC).

● **Robust fragility analysis**: toward d-PBE (dam-Performance Based Engineering).

Thanks for your attention

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