MONIMAN

An overview of the current development

BST/GBT/BK

03.2019

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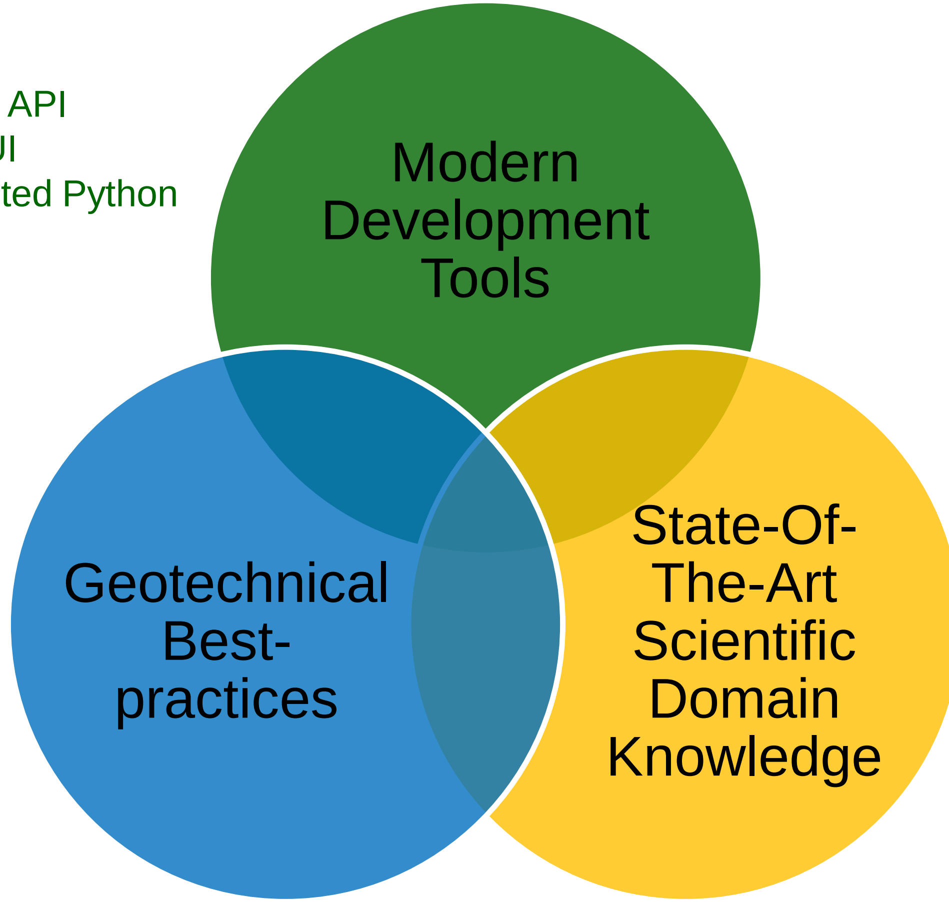
- PLAXIS Python scripting API
- Qt Designer & PyQt5 GUI
- Modularized object-oriented Python programming



- Librabry based properties and features for soils, anchors, struts, etc.
- Process automation for creating calculation steps
- Monitoring data incorporation

- Geotechnical sensitivity analysis and back-analysis
- Cost-driven design optimization
- Metamodeling and machine learning approaches

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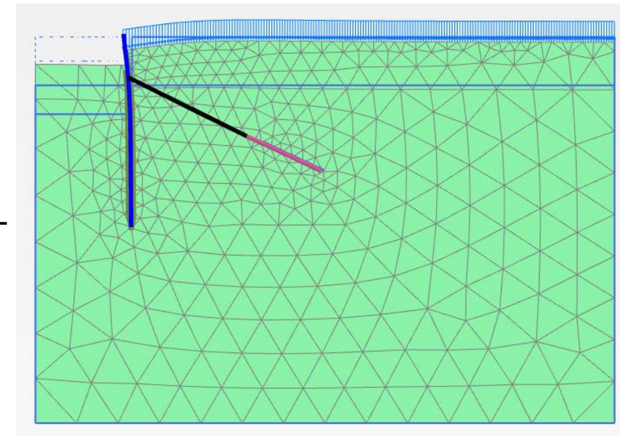
Site

Digital twin (FEM calculation model)



Prognosis

Monitoring data

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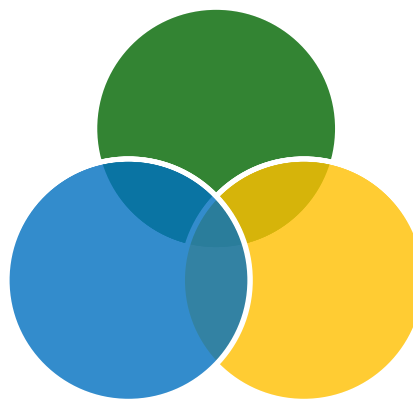

- Model creation
- Model sensitivity analysis
- Model updating (back-analysis)
- Cost-driven design optimization

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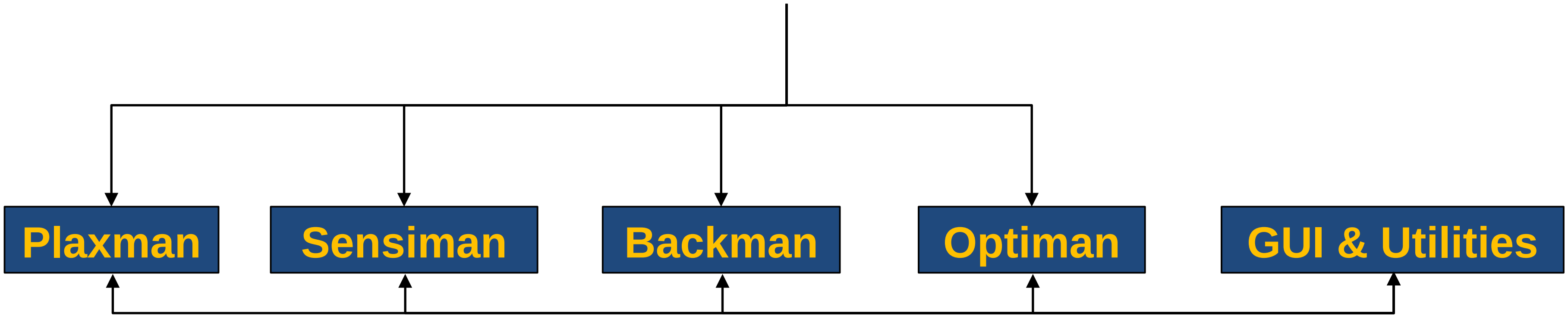
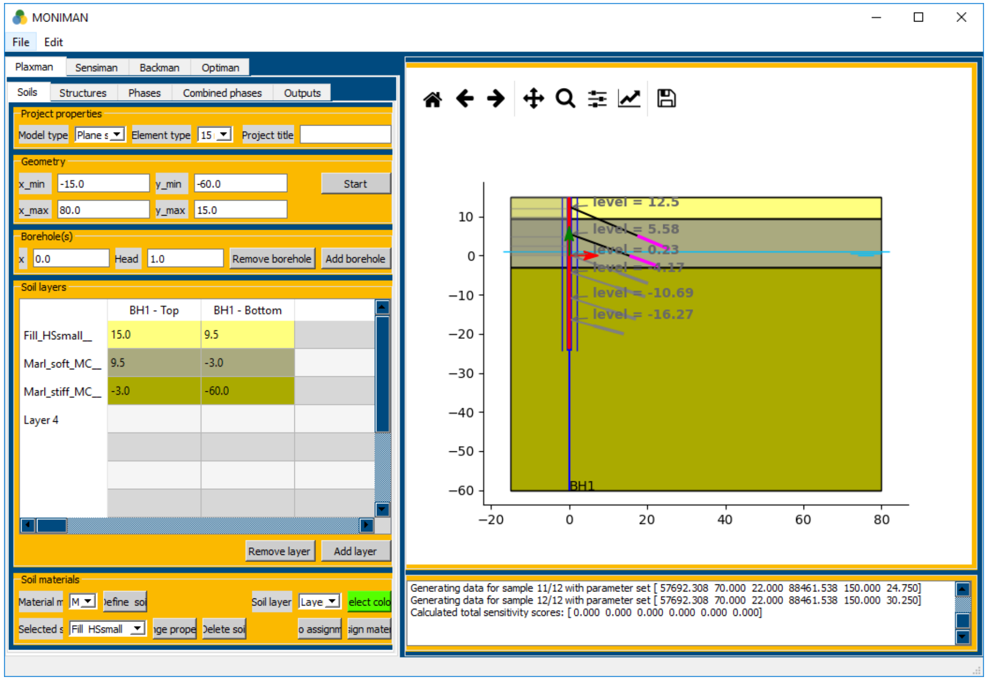
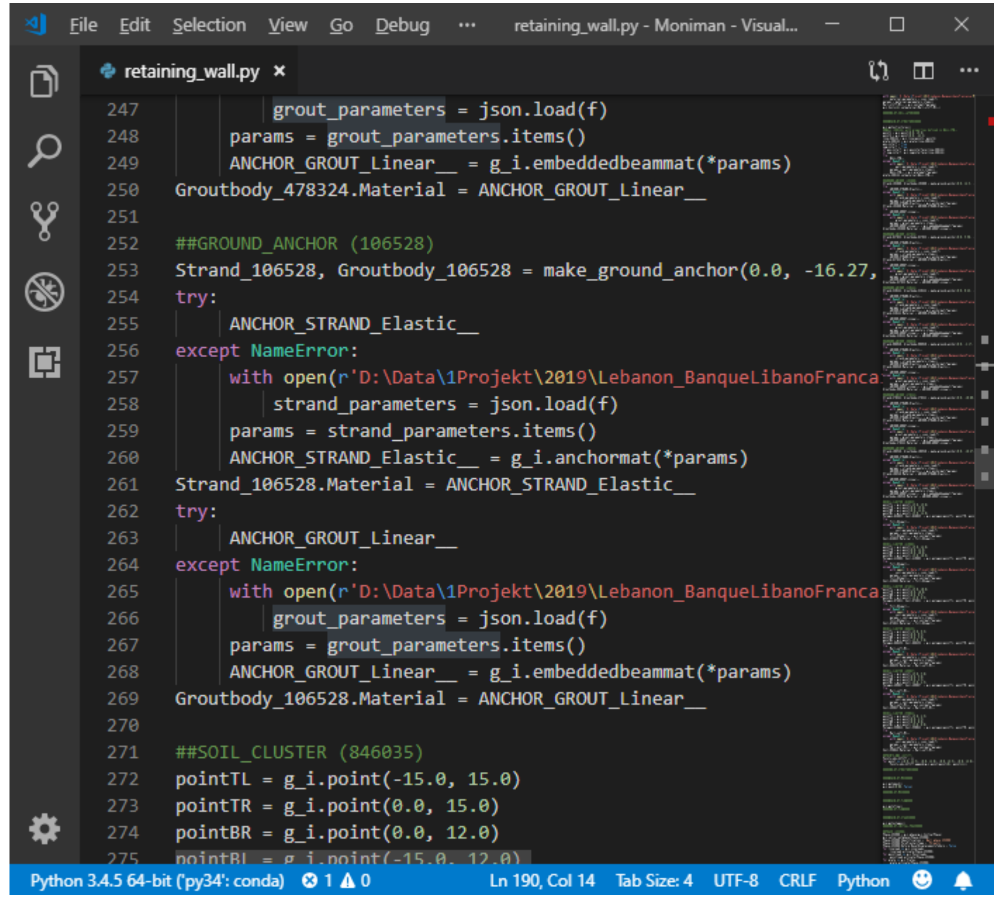


Automate PLAXIS Input & Output	Perform sensitivity analysis of soil/structure parameters to the system	Back-calculate soil parameters by fitting modeled outputs to site measurements	Optimize costs and system performance	User interface/ Communications/ File utilities/ Visualization utilities/ Saving and loading

MONIMAN – Plaxman

Plaxis Remote Scripting with Python





- Predefined soils/ structures to load
- Model creation time is reduced to minutes
- Fully functional: Soils>Structures>Phases>Outputs

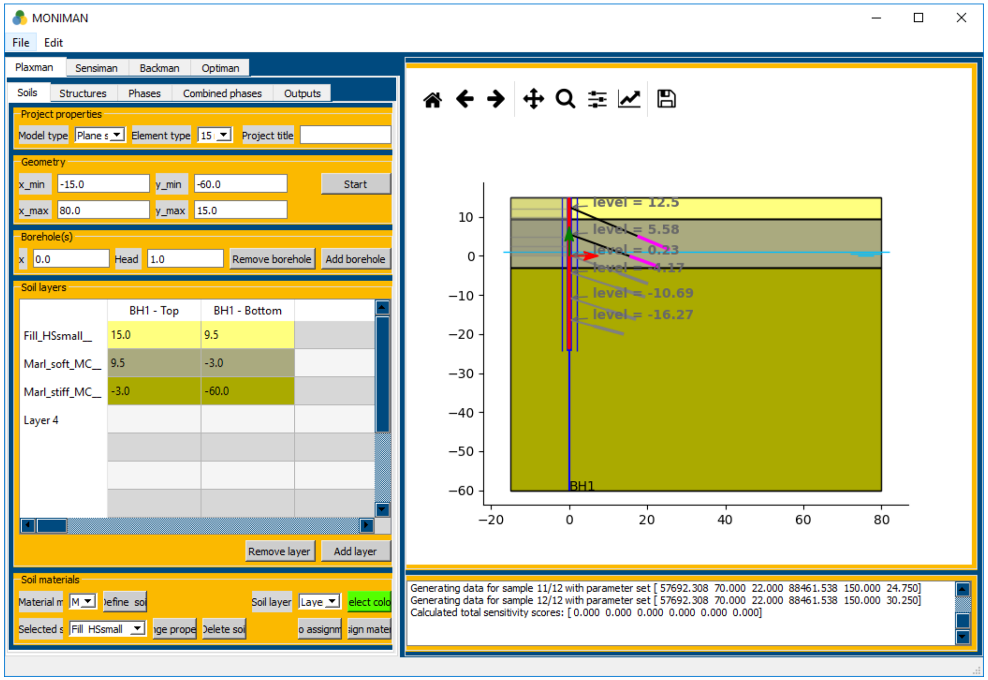
Reference project in Beirut

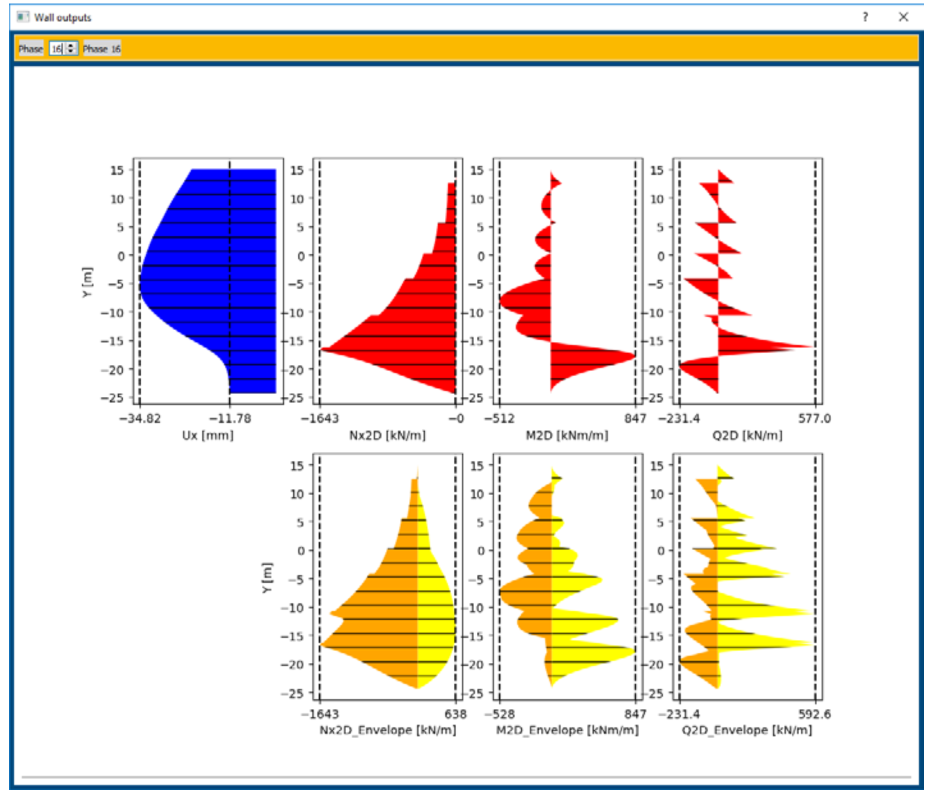
A Python script of the model for further use in

- Sensitivity analysis,
- Backanalysis, and
- Design optimization

MONIMAN – Plaxman

Plaxis Remote Scripting with Python





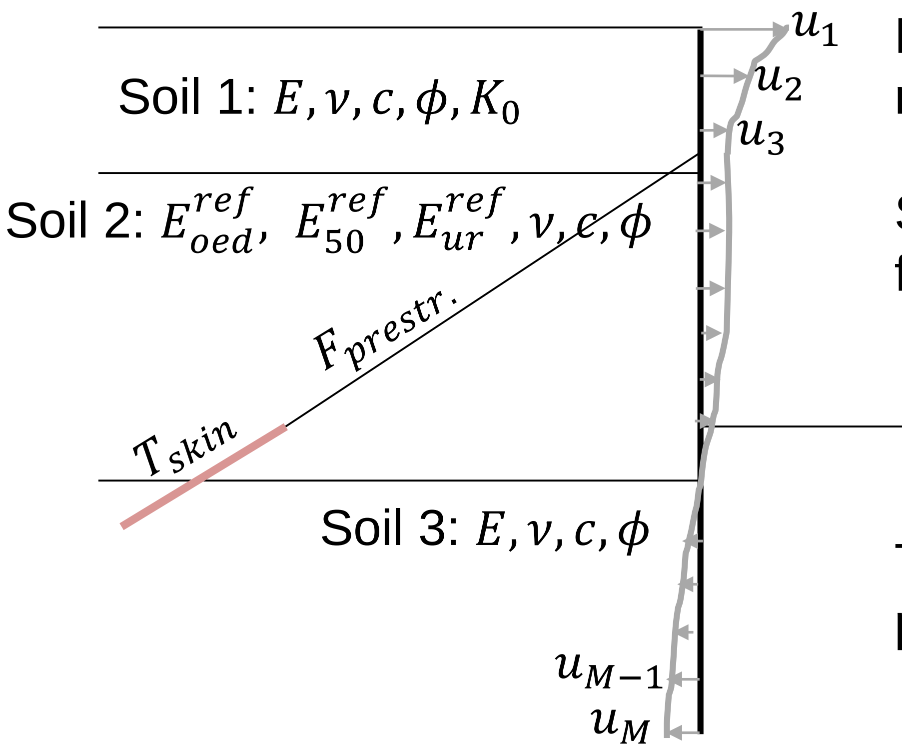
- Predefined soils/ structures to load
- Model creation time is reduced to minutes
- Fully functional: Soils>Structures>Phases>Outputs

Reference project in Beirut

- Requested graphical and numerical outputs for dimensioning
- Repeated model evalutions with updated model parameters for sensitivity analysis, back-analysis, and design optimizatoin.

MONIMAN – Sensiman

Sensitivity analysis of system parameters to certain system responses



How much is the influence of each model parameter to wall deflection?

Sensitivity score w.r.t. parameter m_i for 1 measured point:

$$ss_i = \frac{\partial u_1}{\partial m_i} m_i$$

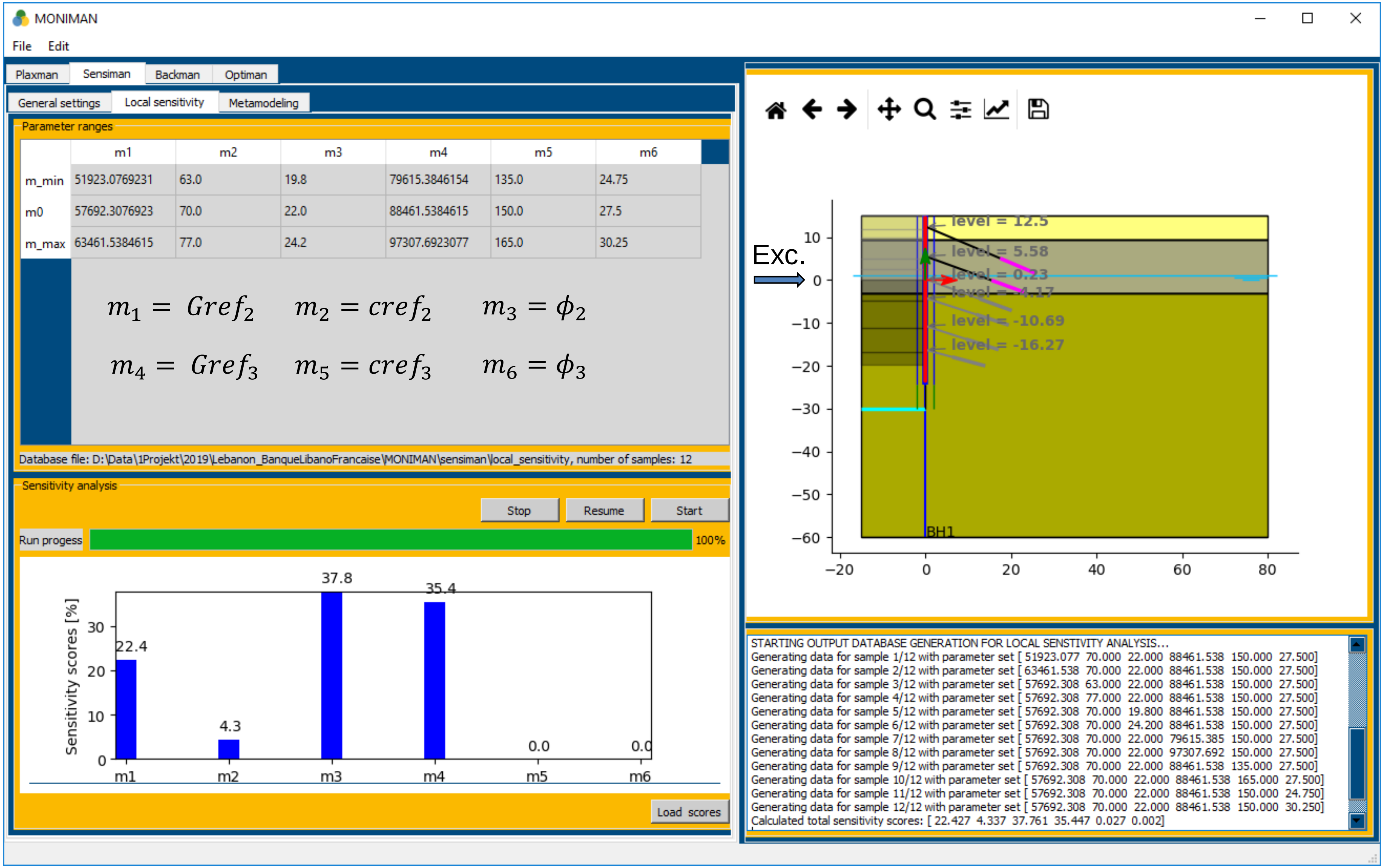
Total sensitivity score w.r.t. parameter m_i for all measured points:

$$tss_i = \left[\sum_j \left(\frac{\partial u_j}{\partial m_i} m_i \right)^2 \right]^{1/2}$$

Choose the most sensitive parameters for performing back-analysis.

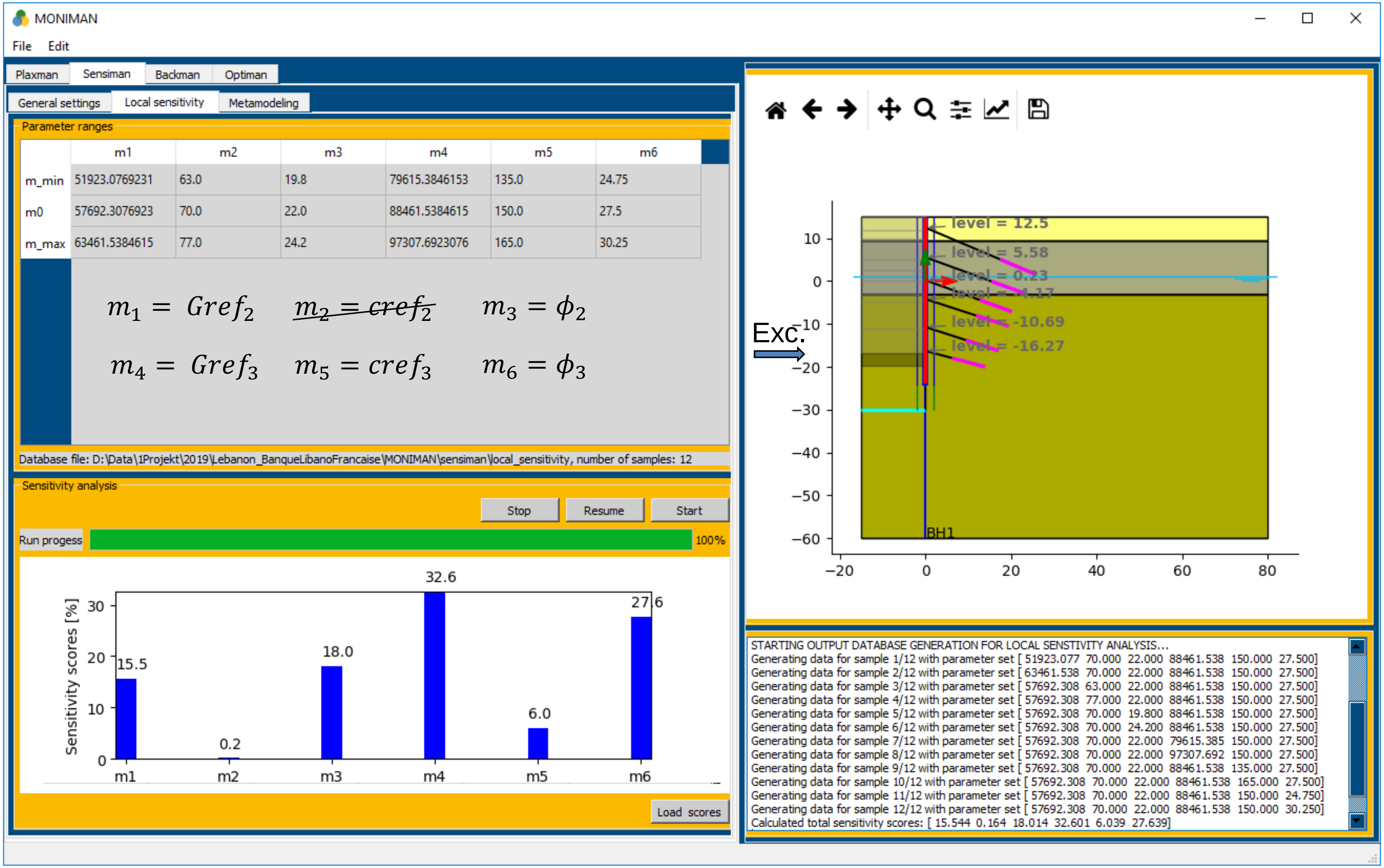
MONIMAN – Sensiman

Local sensitivity analyiss



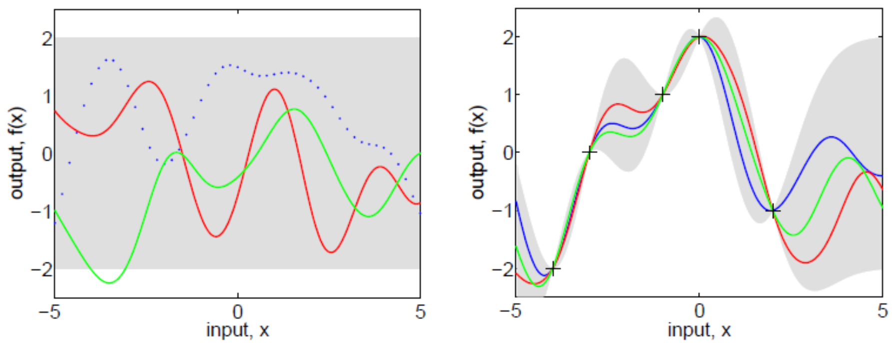
MONIMAN – Sensiman

Local sensitivity analyiss



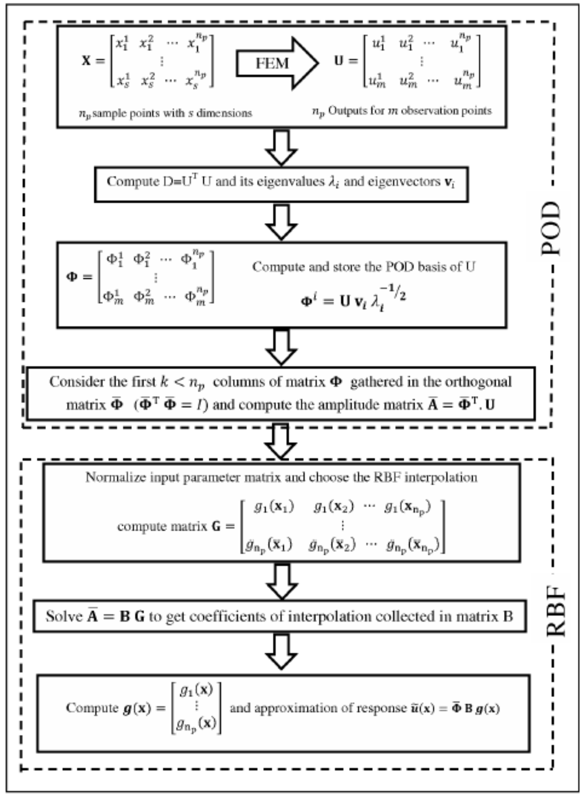
MONIMAN – Sensiman

Metamodel instead of FE model



(a), prior (b), posterior

Gaussian process (GP)
(Rasmussen and Williams, 2006)

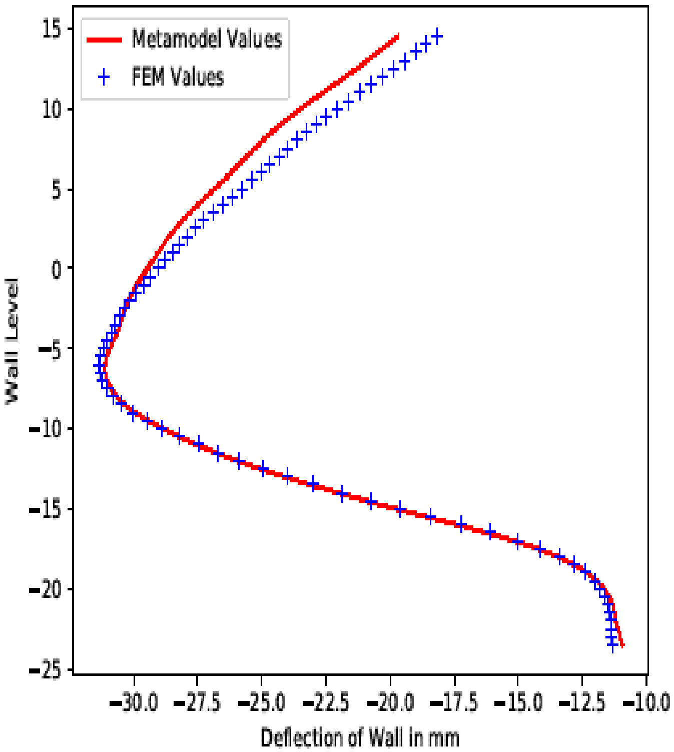


Proper orthogonal decomposition (POD) + radial basis function (RBF) (Khaledi and Schanz, 2014)

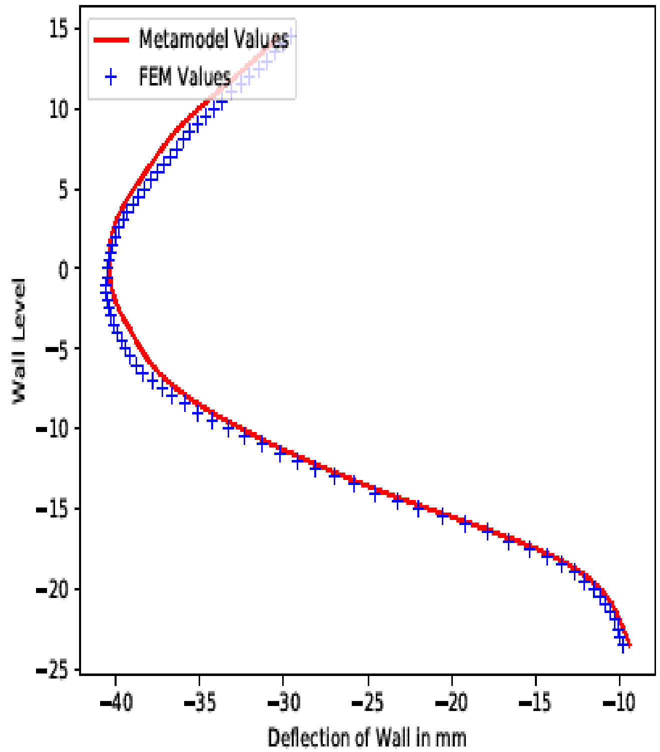
On-going Master‘s thesis work: Mohammad Sanayei

MONIMAN – Sensiman

Metamodel instead of FE model



$Gref_2, \phi_2, Gref_3, cref_3, \phi_3 =$
[66133, 24.7, 87293, 169.9, 27.5]



$Gref_2, \phi_2, Gref_3, cref_3, \phi_3 =$
[37842, 17.0, 115738, 184.6, 17.7]

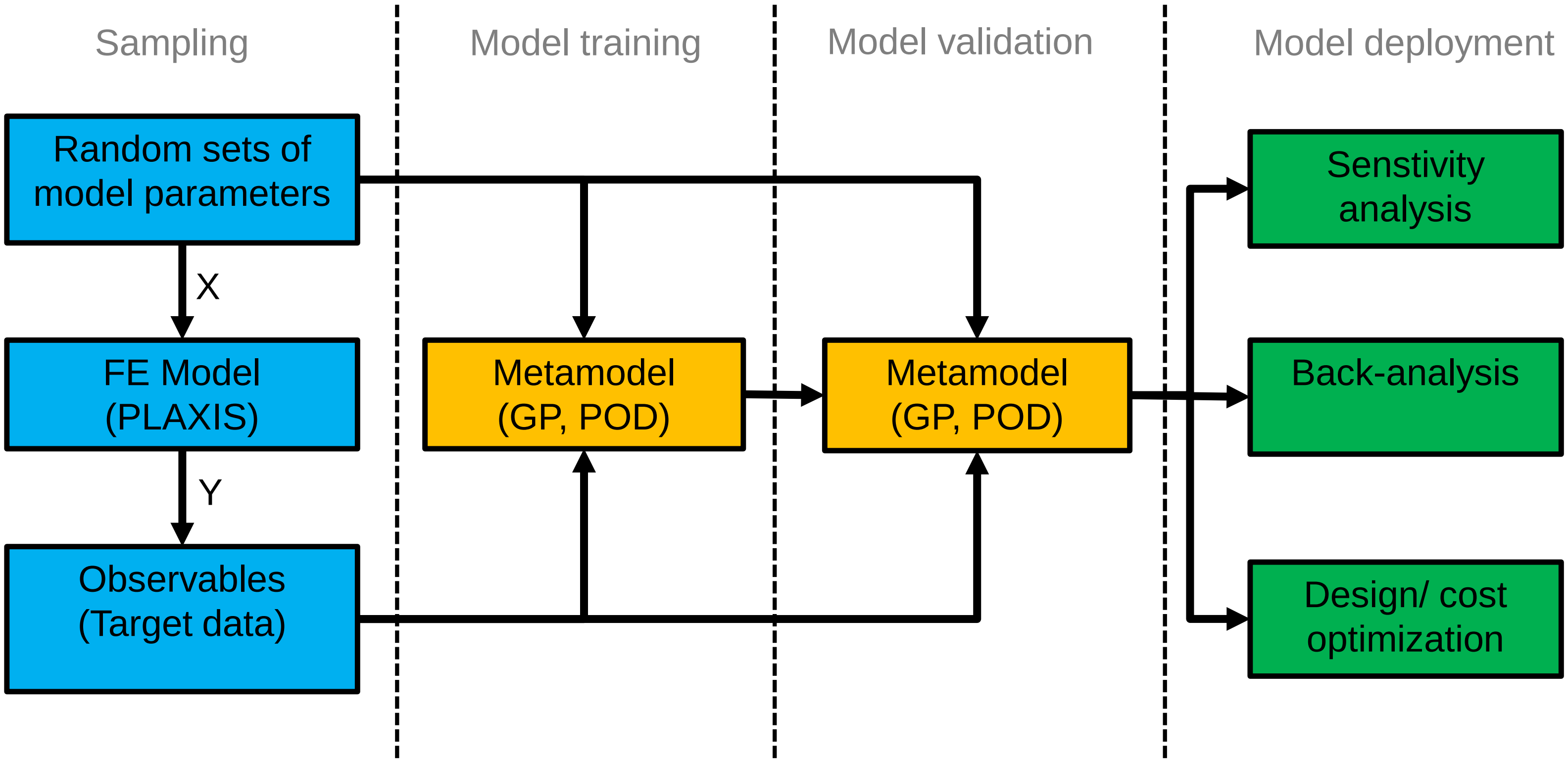
Evaluation time:

- FE model : ~4 min.
- Metamodel: ~1 millisec.

Metamodeling by Gaussian Process using 250 training samples + 30 testing samples

MONIMAN – Sensiman

Metamodel instead of FE model

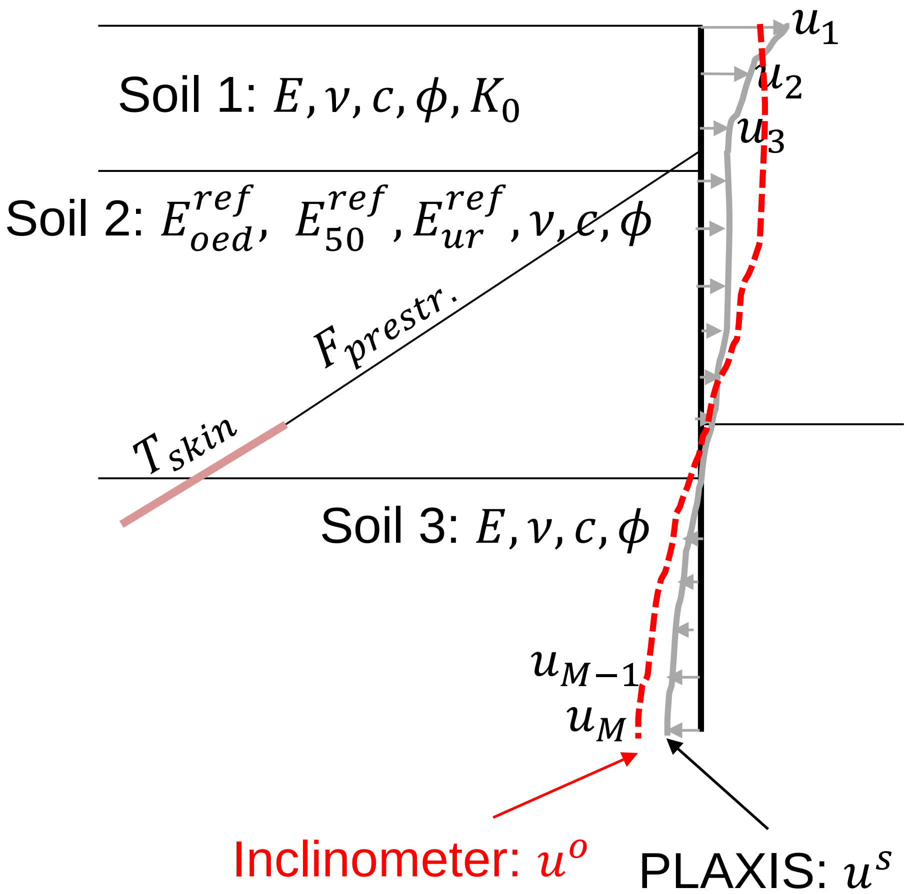


Why is metamodel beneficial?

- Well-designed random sampling method (such as Latin Hypercube) helps reduce the sampling size yet cover the design (parameter) space
- The result of one-time upfront efforts (FE simulations + training + validation) is used for demanding investigations that follow (sensitivity, back-analysis, design optimization)

MONIMAN – Backman

Geotechnical back-analysis



Back-analysis is to fit u^s to u^o by repeatedly changing soil/ structure parameters by an optimization algorithm.

Back-analysis is a challenging ill-posed inverse problem:

- Measurement noise
- Soil variabilities (inhomogeinity) and mechanical behaviors that are not captured by soil models (anisotropy)
- Other modeling uncertainties (soil-structure interactions, no real loads)

Many numerical optimization algorithms: **Kalman filters** (KF), **Particle swarm optimization** (PSO), etc.

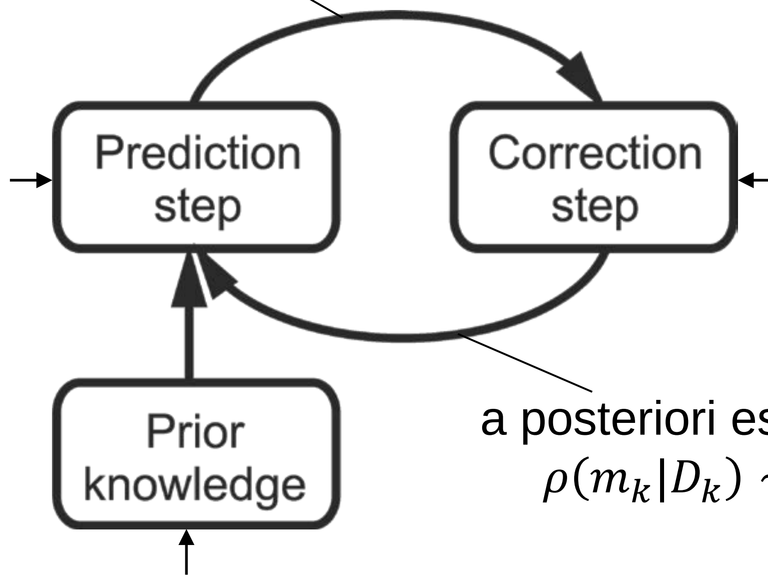
Numerical algorithms back-calculate soil/ structure parameters by fitting modeled outputs to measured site data using as few model evaluations as possible.

MONINAN – Backman

Kalman filter for geotechnical back-analysis

a priori estimate: $\rho(m_k|D_{k-1}) \sim N\left(m_{k|k-1}, P_{k|k-1}\right)$

model: $d = h(m) + v$



data: $\rho_D(d) \sim N\left(d^{obs}, R^{obs}\right)$

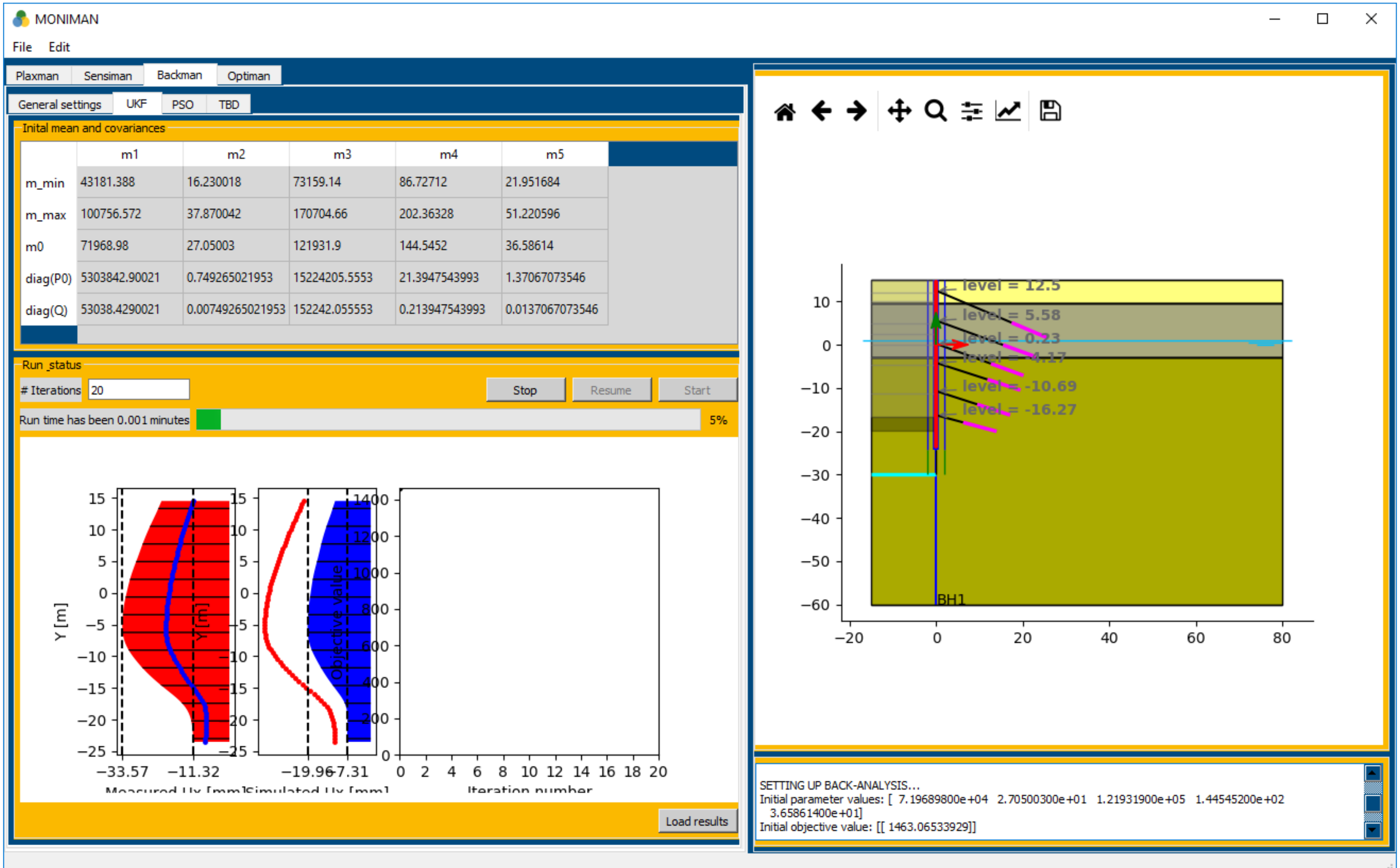
a posteriori estimate (Bayes′ theorem):
$\rho(m_k|D_k) \sim \rho(d_k|m_k)\rho(m_k|D_{k-1})$

initial estimate: $\rho_M(m) \sim N(m_0, P_0)$

Nguyen, L.T., Nestorović, T., Hölter, R. and Schanz, T., Identifying the geological scenario ahead of the tunnel face: The use of elastoplastic and elastodynamic responses. Geotec Hanoi 2016.

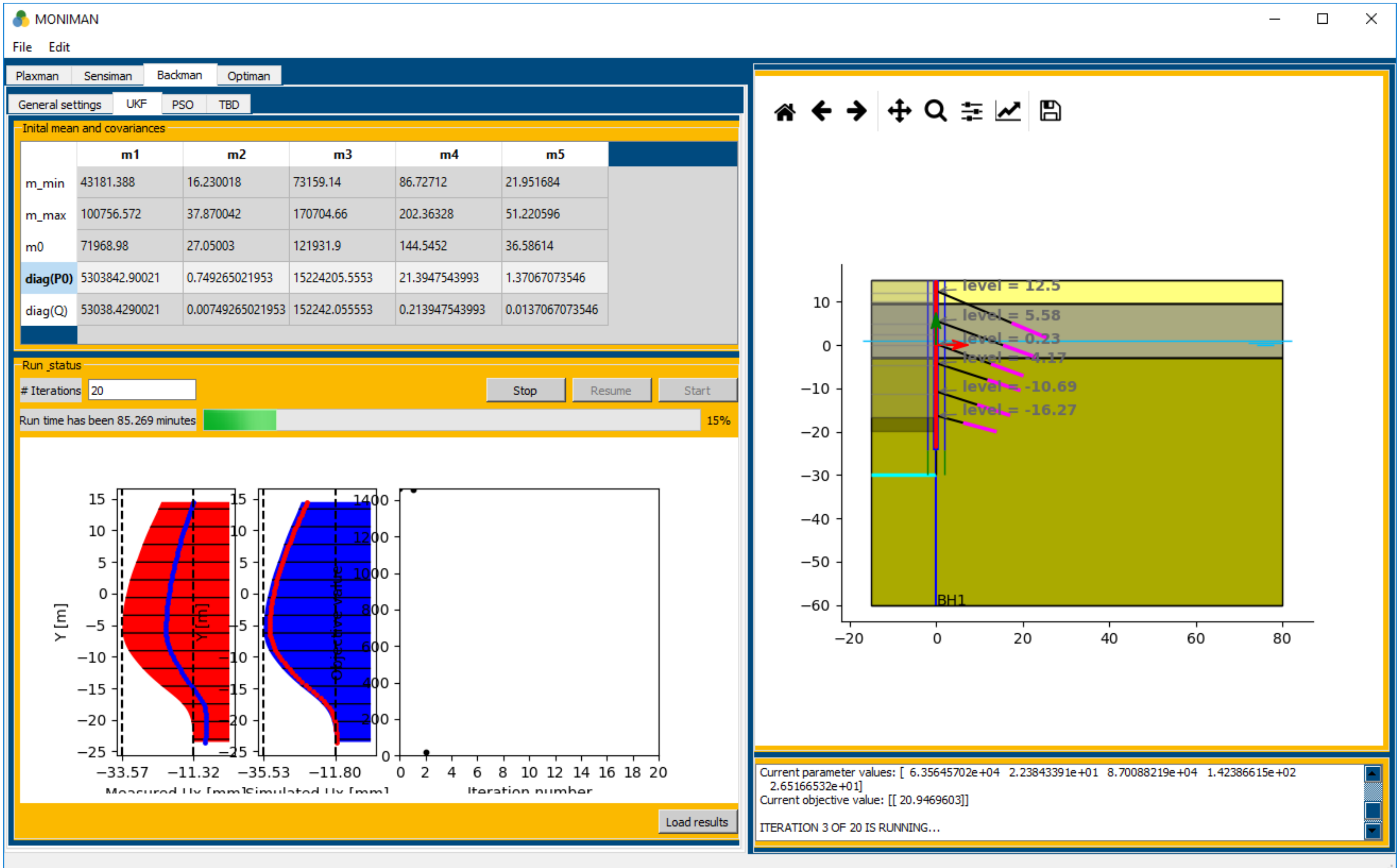
MONIMAN – Backman

Kalman filter for geotechnical back-analysis



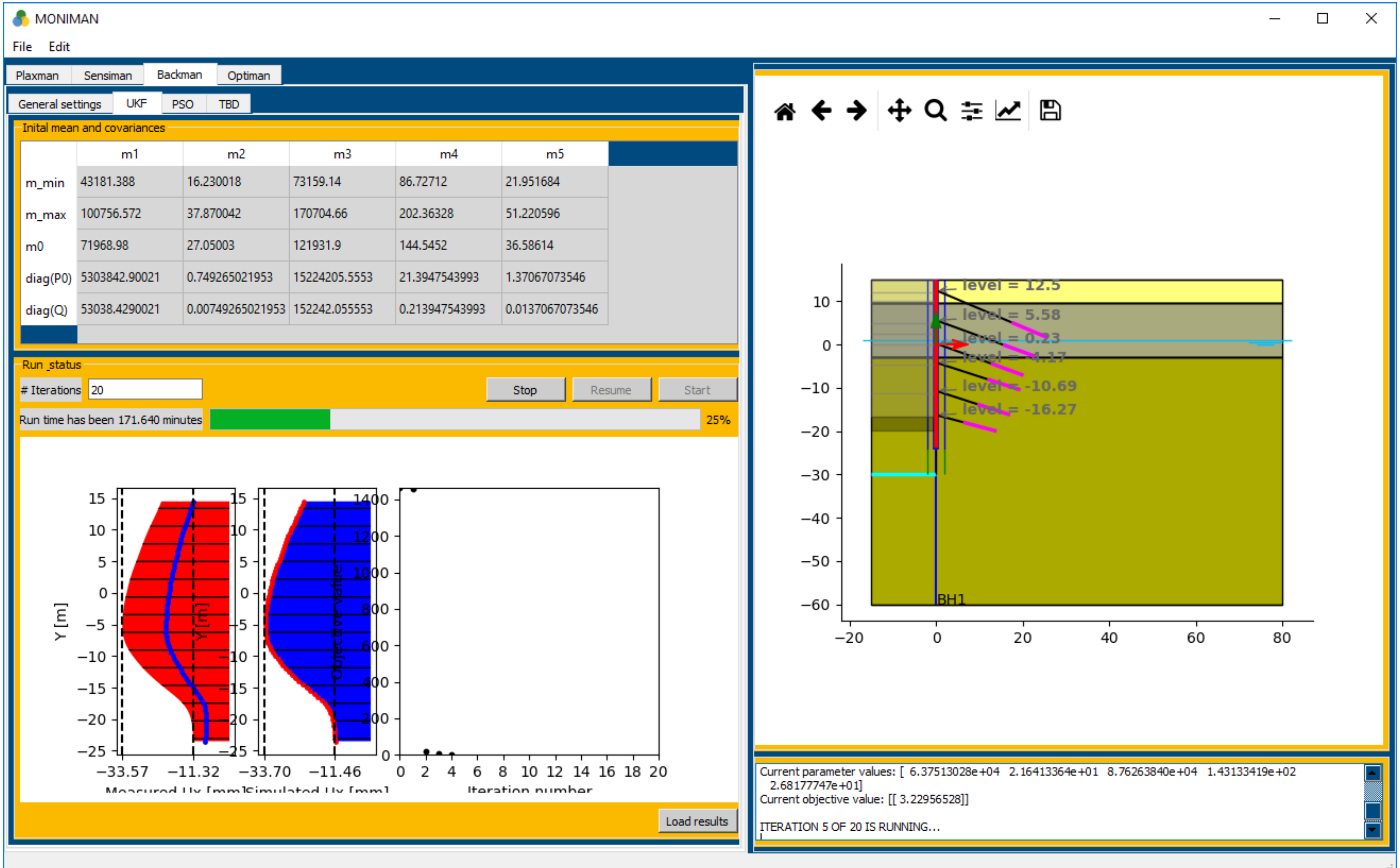
MONIMAN – Backman

Kalman filter for geotechnical back-analysis



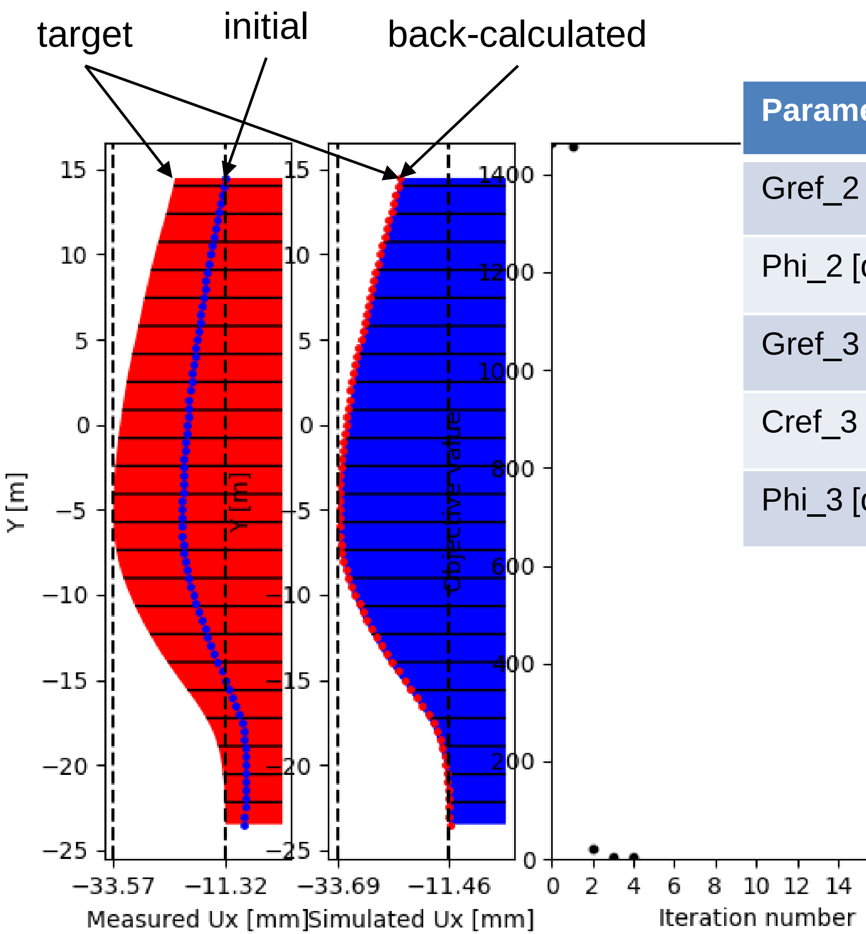
MONIMAN – Backman

Kalman filter for geotechnical back-analysis



MONIMAN – Backman

Kalman filter for geotechnical back-analysis

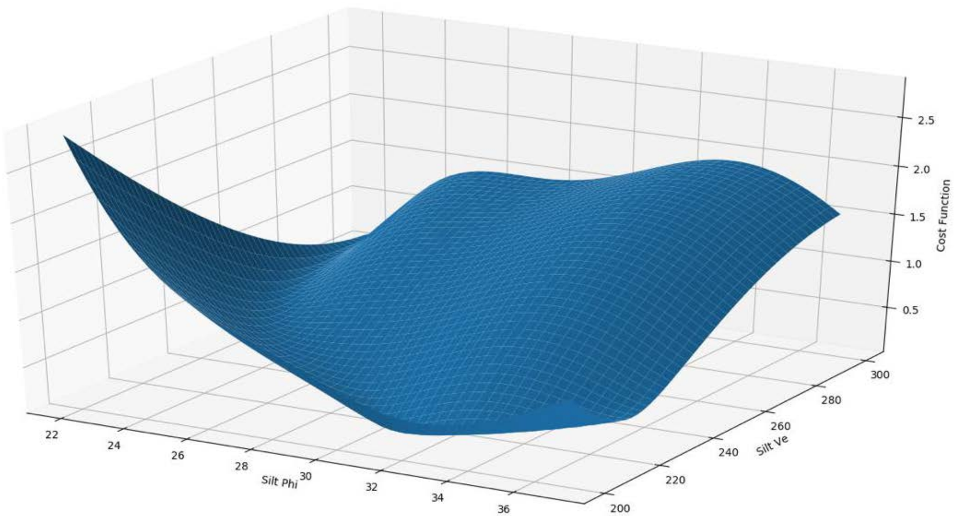


Parameter	Initial	Back-calculated	True	Deviation (%)
Gref_2 [kN/m^2]	71968,98	63751,30	57692,30	9,50
Phi_2 [deg.]	27,05	21,64	22,00	1,66
Gref_3 [kN/m^2]	12193,90	87626,38	88461,53	0,95
Cref_3 [kN/m^2]	144,54	143,13	150,00	4,79
Phi_3 [deg.]	36,58	26,81	27,50	2,57

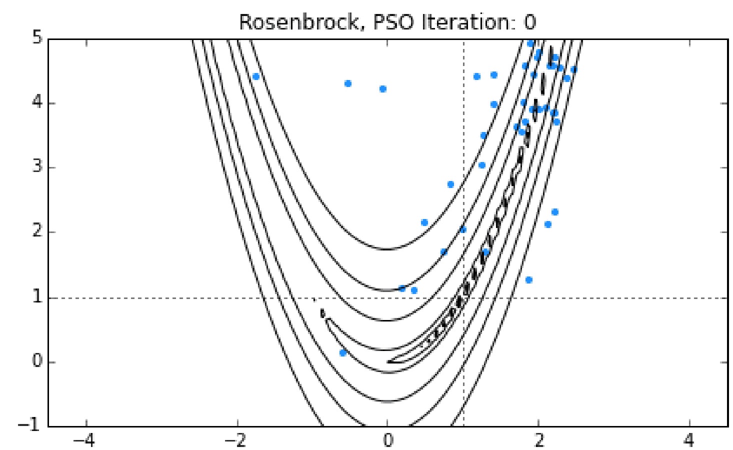
4 iterations * (2*number_of_parameters + 1) = 44 PLAXIS2D runs

MONIMAN – Backman

Particle swarm optimization (PSO) for geotechnical back-analysis



Typical back-analysis‘ multi-minima objective function



https://cosmo-docs.phys.ethz.ch/cosmoHammer/user/pso.html

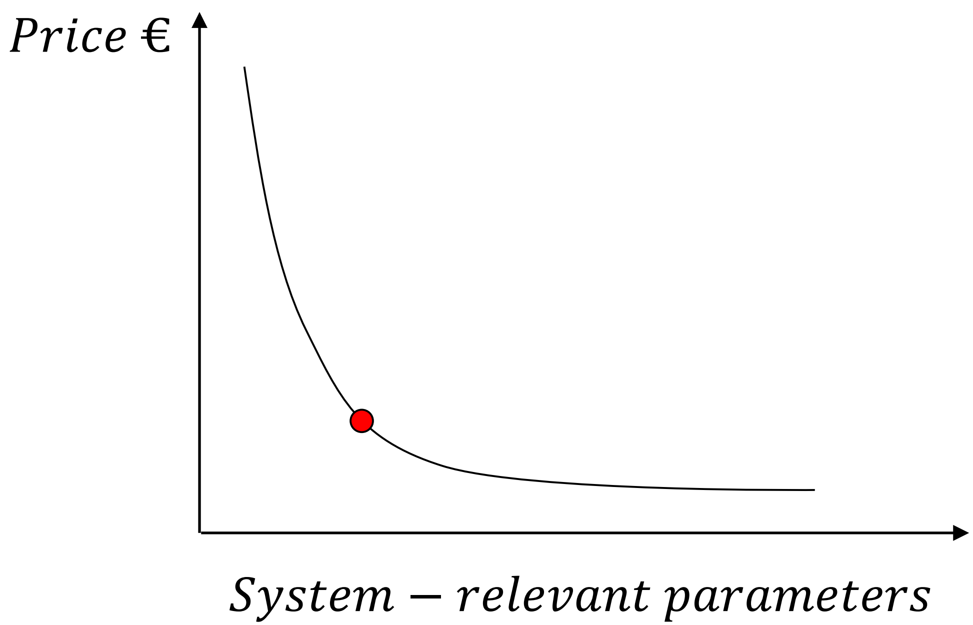
On-going Master‘s thesis work: Mohammad Sanayei

MONIMAN – Optiman

Design/ cost optimization

Automated design optimization process taking into account material and execution costs.

How far can we go to reach most economic design while still satisfying system behavior?



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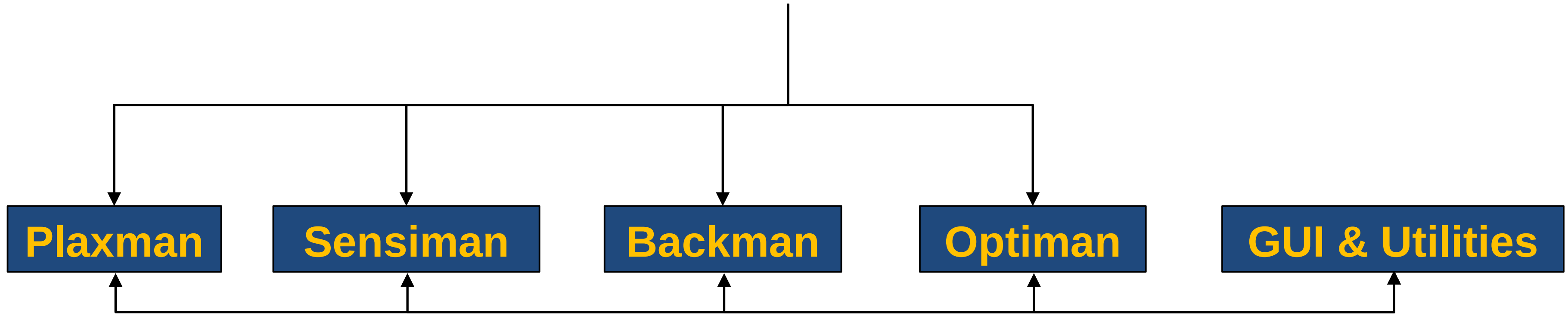


Plaxman: Model creation, Calculation and output

Sensiman: Sensitivity analysis, Metamodeling

Backman: Kalman filter, Particle swarm opt.

Optiman: Design optimization

GUI & Utilities: User interface, File management, Visualization and report

Numbers

6 months
20420 code lines

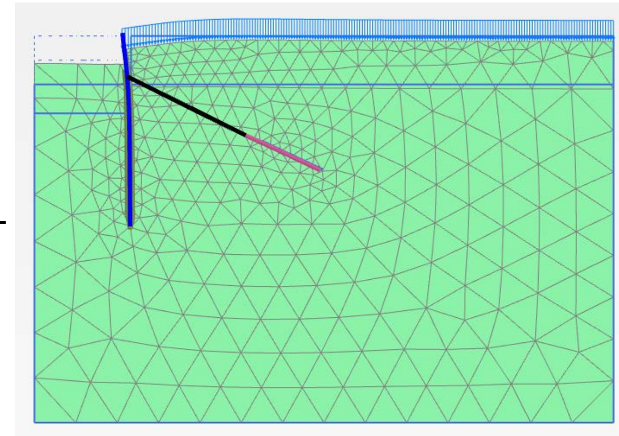
Lessons learned

- Modern development framework and librabries (`OOP Python, PyQt5, numpy, matplotlib, pickle, json, etc.`) help shorten development time
- Modularized structure helps in mantainaning and extending functionalities of MONIMAN
- Careful use of results in scientific publications and public-domain resources can be beneficial
- User experience and feedback are valuable

MONIMAN

Site

Digital twin (FEM calculation model)



Prognosis

Monitoring data

MONIMAN

- Model creation
- Model sensitivity analysis
- Model updating
- Cost-driven design optimization

MONIMAN: Optimization-based tool to turn monitoring data into valuable design parameters that can help to minimize the cost while securing safe design.

Thanks to members of the BK Department for great support and input!

Thank you for your listening!

Your comments/ questions are welcome.