Time history dynamic analyses of geotechnical structures

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Overview

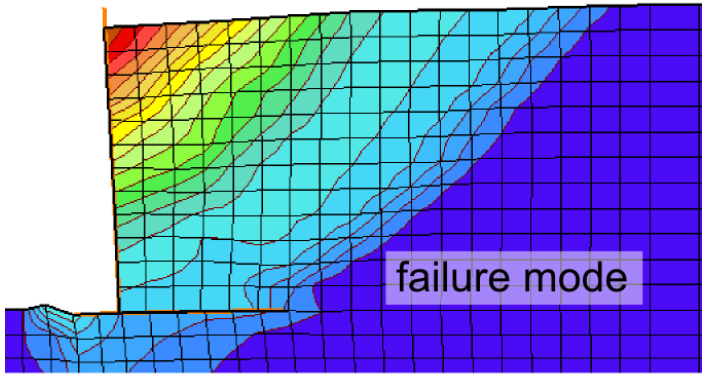
- Retaining walls
- Current practice in CH (within GeoMod, norms)
- Comparison replacement force (RF) method - time history (TH)

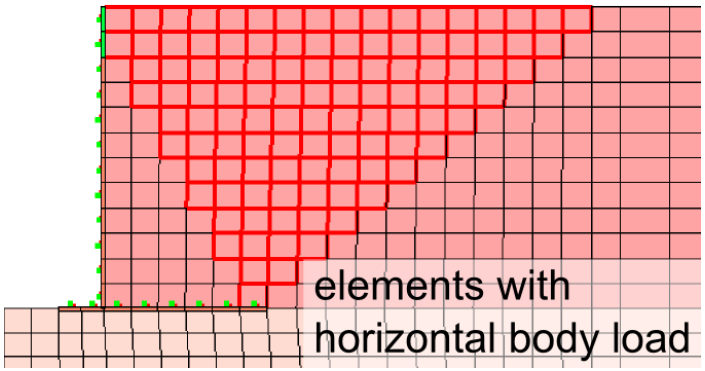
-> RF method is overly conservative

-> TH on 2D model can be good alternative

Retaining walls: Norm SIA 261 & 267(proposed)

- Replacement force method:
  - Applied to structure and part of adjacent soil, corresponding to failure mechanism (SIA267§7.4)





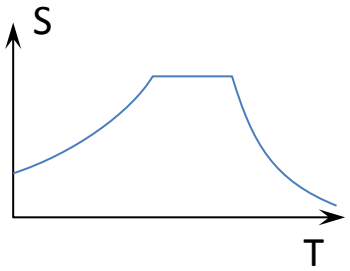
Retaining walls: Norm SIA 261 & 267(proposed)

- Replacement force method:
  - Force: $$A_{h,d} = \gamma_f \frac{a_{g,d}}{g q_a q_h} \cdot S \cdot G_K$$

γ_f: Importance
$a_{g,d}/g$: Ground acceleration
q_a & q_h: Coefficients accounting for ductility and spatial extension/variability

1.0 - 2.0 ~1.0

S: Design spectrum -> generally plateau value
G_K: Mass



Retaining walls: Norm SIA 261 & 267(proposed)

- Replacement force method:
  - Force: $A_{h,d} = \gamma_f \frac{a_{g,d}}{g q_a q_h} \cdot S \cdot G_K$

- Leads to very conservative design!
- No useful for estimating deformation

γ_f: Importance
$a_{g,d}/g$: Ground acceleration
q_a & q_h: Coefficients accounting for ductility and spatial extension/variability

1.0 - 2.0 ~1.0

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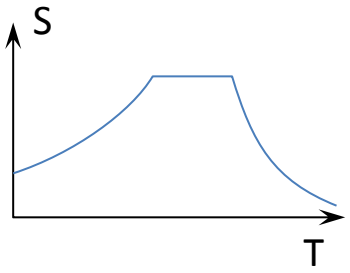
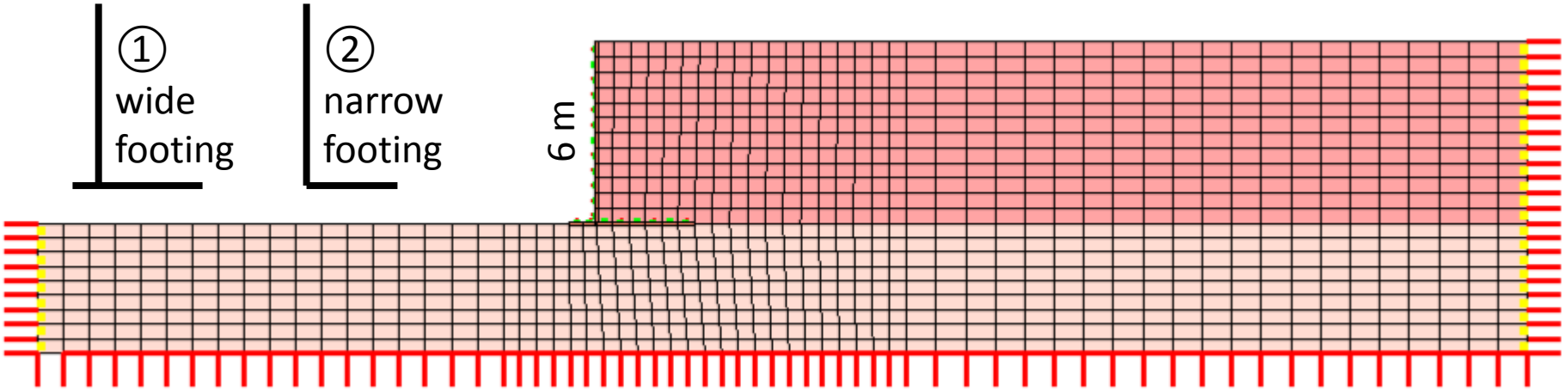


Non-linear analysis in time domain

- Not covered in SIA or EC (some guidelines exist for e.g. dams and highway infrastructures)
- Guidelines in e.g. Kramer, Geotechnical Earthquake Engineering, 1996.
  - Discretization (time, space)
  - Boundary conditions (free/fixed, absorbing, more advanced methods)
- Zsoil report (Menu Help->Reports->Dynamics)
- Topic of active research

FE-Model of retaining wall



- Rigid base, horizontal seismic motion applied by changing reference frame:

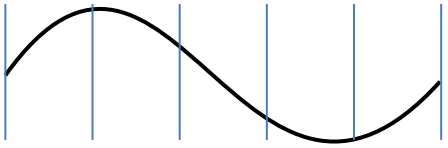
$$M\ddot{x} + C\dot{x} + Kx = F \rightarrow \ddot{x} = \ddot{x}_{rel} + \ddot{x}_g \rightarrow M\ddot{x}_{rel} + C\dot{x} + Kx = F - M\ddot{x}_g$$

- Absorbing lateral boundaries

Discretization

- **Mesh size**: 5-10 nodes per shortest wavelength

$$h^e \leq \frac{\lambda_{min}}{\{5-10\} \cdot v_s} \qquad \lambda_{min} = \frac{v_s}{f_{max}}$$



where f_{max} depends on the application. For typical seismic records f_{max} = 10-20 Hz.

- **Time step length**: 5-10 steps per shortest period

$$\Delta t \leq \frac{h^e}{v_s}$$

or, a wave should not travel through more than one *element per time step*

Algorithm & Damping

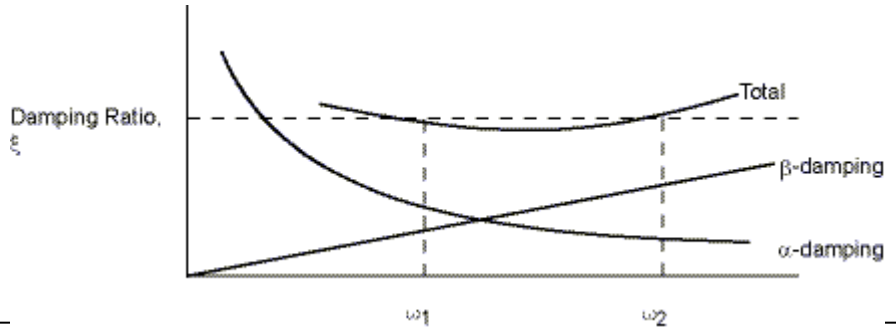
- Distinguish between physical and numerical damping

- Physical damping in the model:
  - Energy dissipation:
    - Plasticity
    - Nonlinear elasticity (HSS)
  - Absorbing boundaries: Simulate radiation damping

Algorithm & Damping (cont.)

- Use HHT-Algorithm to numerically damp/eliminate high frequencies (noise)

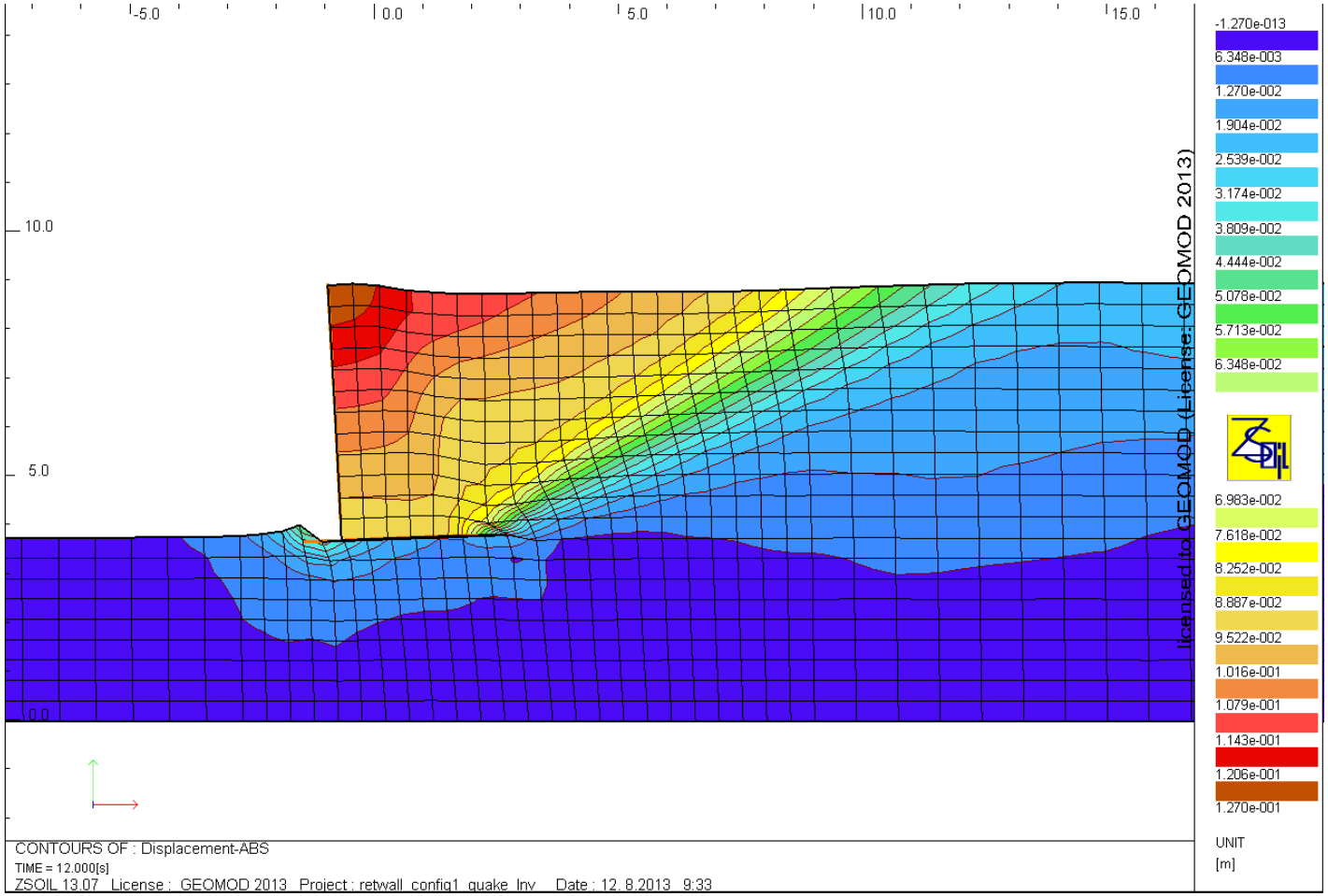
- Rayleigh damping:
  - Small amount can be necessary for numerical reasons
  - Careful with mass-proportional damping (α_0 in ZSoil): Low frequencies
    are exessively damped!



Interpretation of results

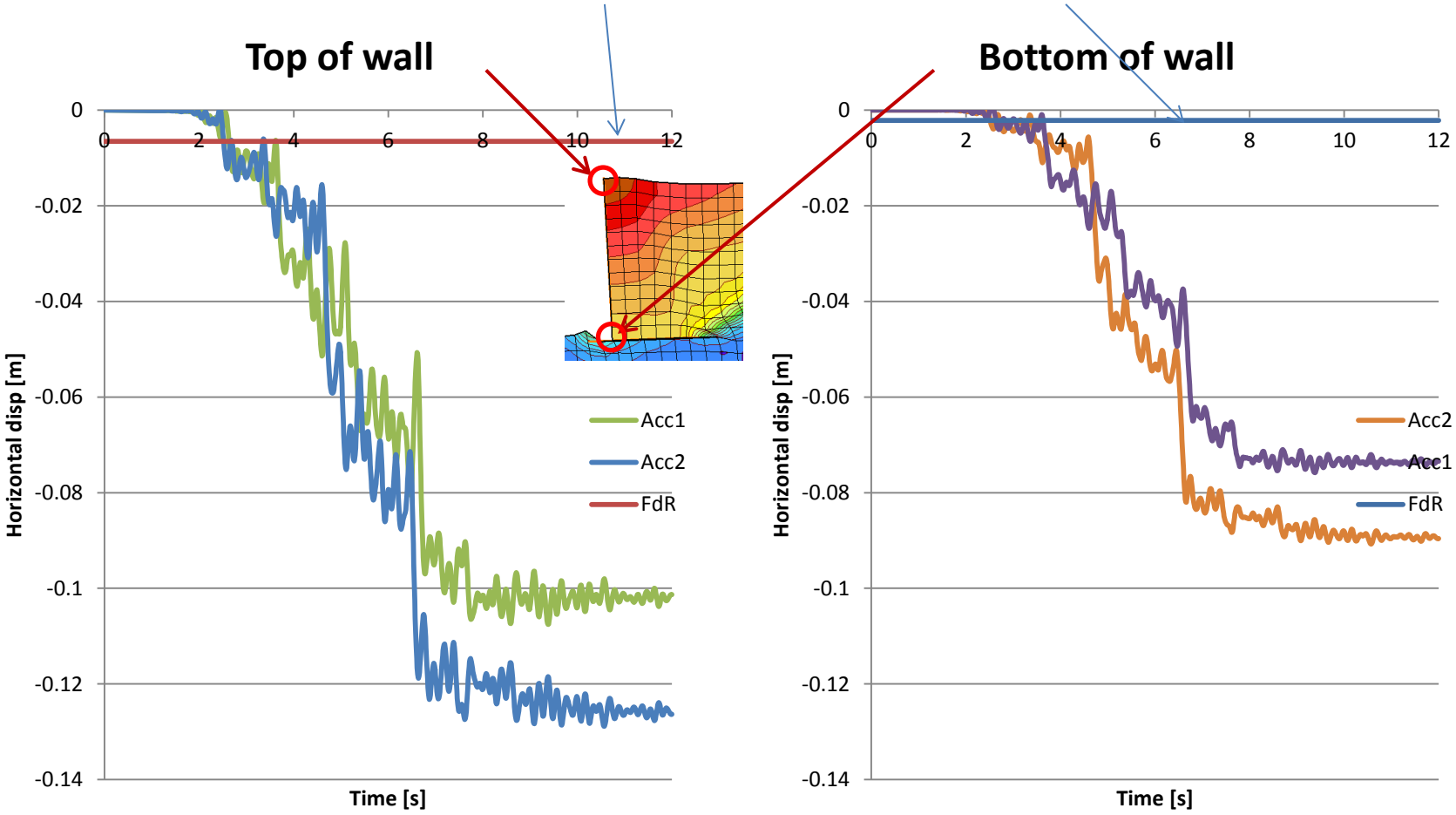
- Minimum 3 accelerogrammes (generated artificially, recorded at similar sites)
- 5 or more:
  - Mean + std.dev * factor (e.g. Student-Fisher average)
- Fewer than 5:
  - Max/min values
  - If differences between accelerogrammes are big, consider selecting more accelerogrammes

Wide footing, TH-analysis

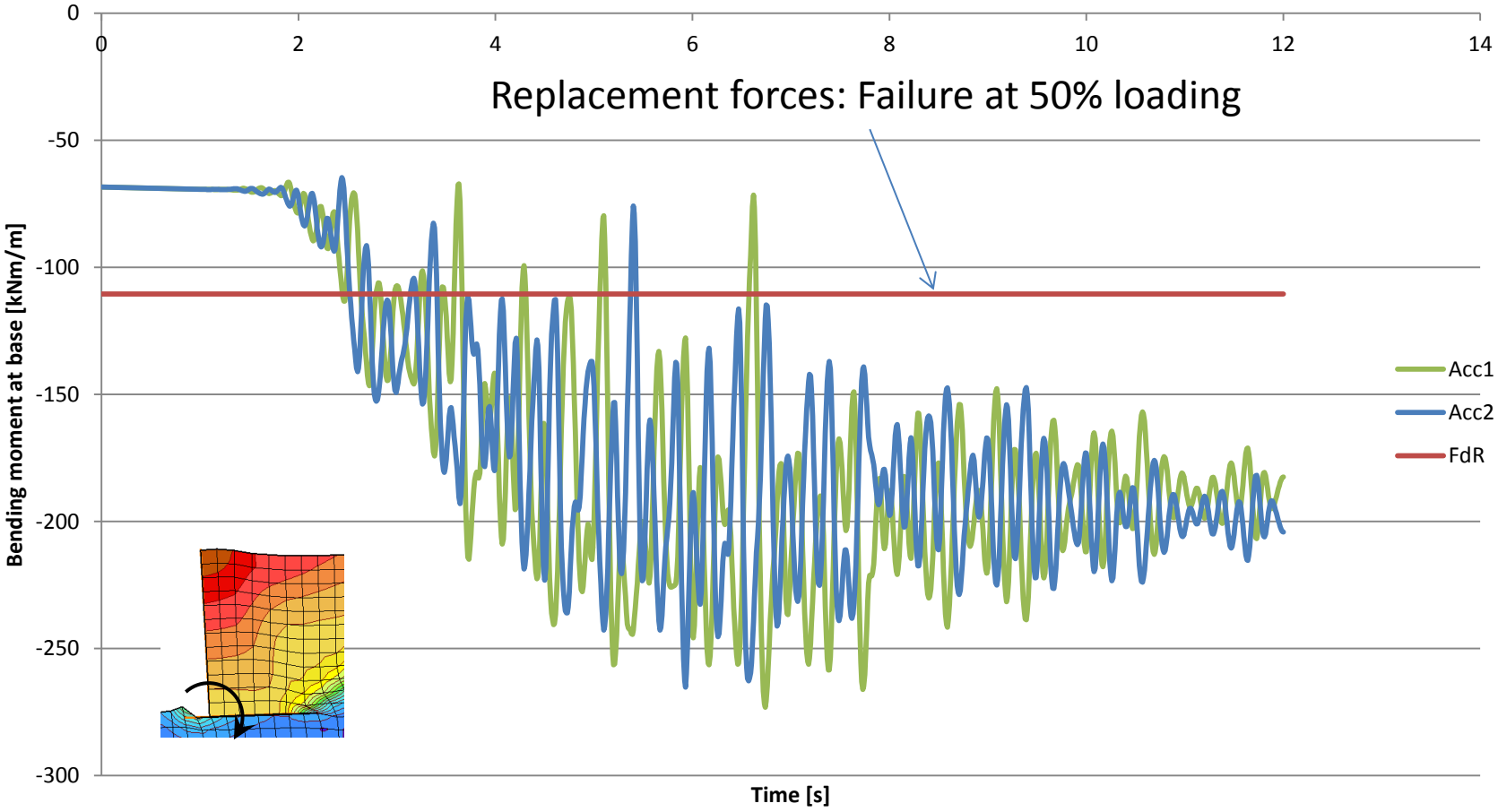


Wide footing, displacements

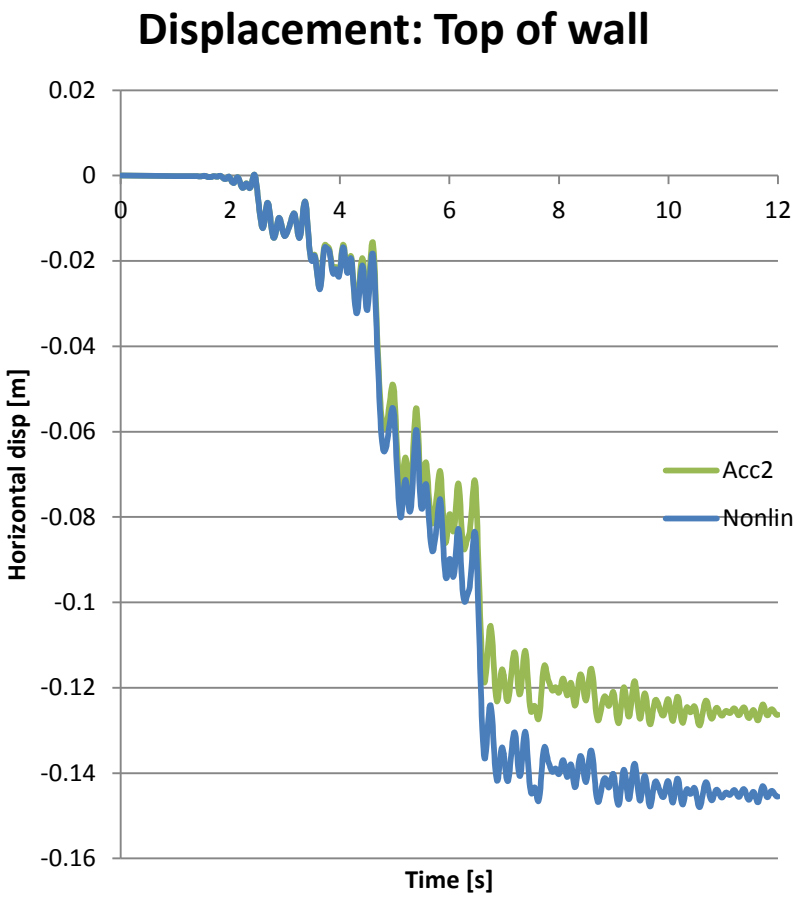
Replacement forces: Failure at 50% loading

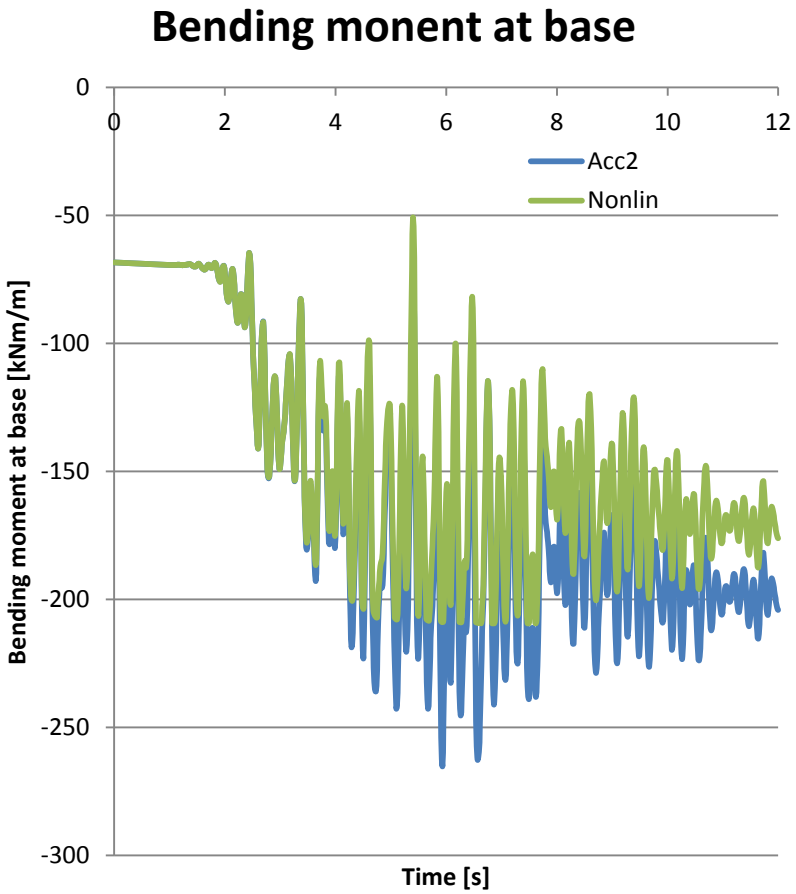


Wide footing, bending moments



El-pl retaining wall (M_{pl} = 210kNm/m)





Conclusions

- RF method is overly conservative
- TH is only method that correctly accounts for nonlinearities (plasticity, contact, nonlinear elasticity etc.)
- Zsoil is capable of computing TH for EQ-loading
  - All commonly used numerical tools are available
  - 2D models can easily be computed on laptop PC