Numerical analysis of dams

ICOLD-BW 2019
9th-11th September
MILANO

CIGB ICOLD

10th September 2019

Theme B:
Seismic analyses of Menta Embankment dam

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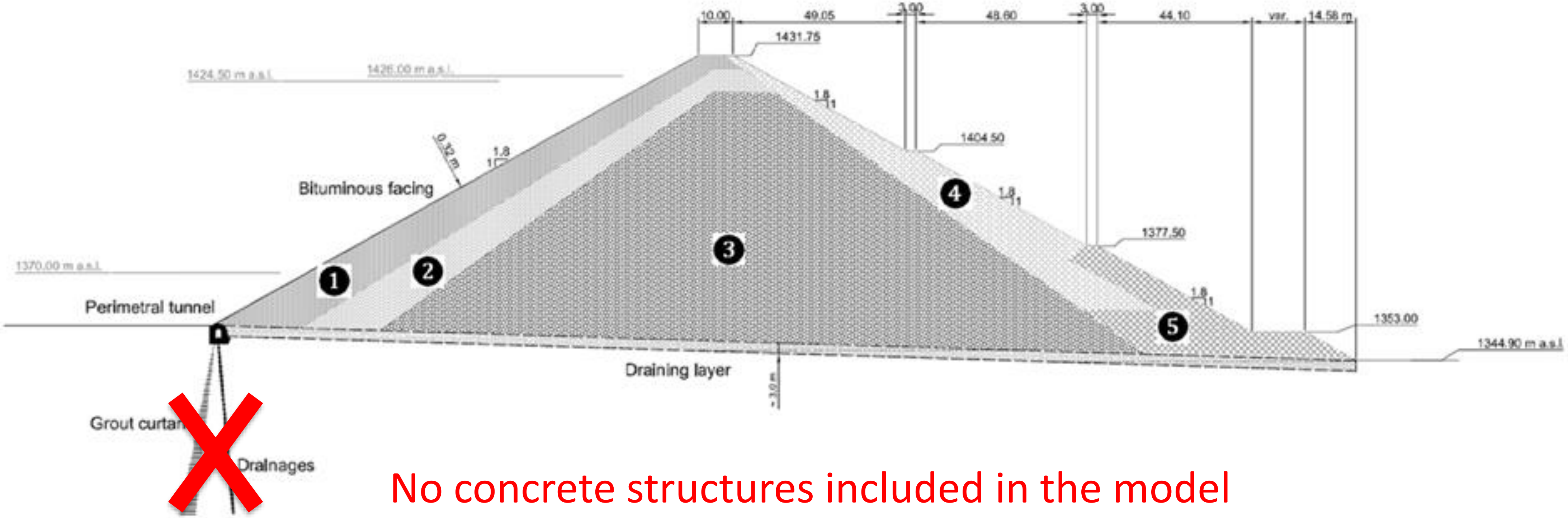
Geometry



No concrete structures included in the model

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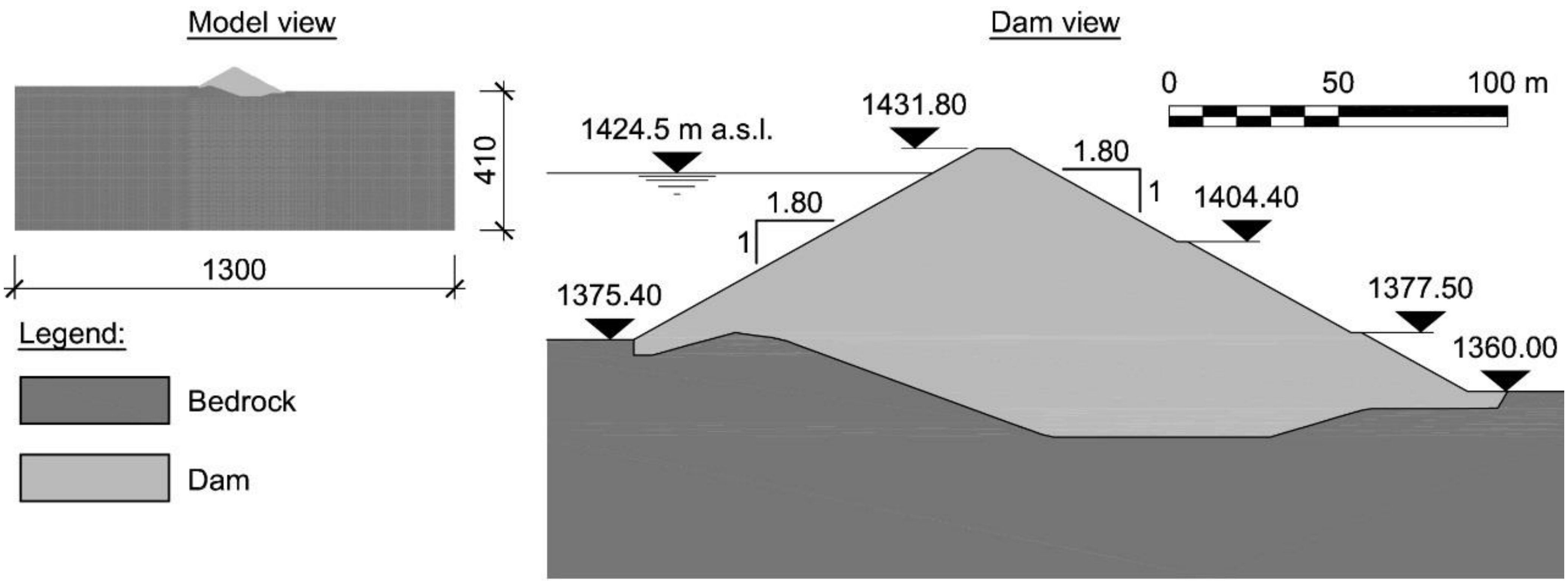
Geometry



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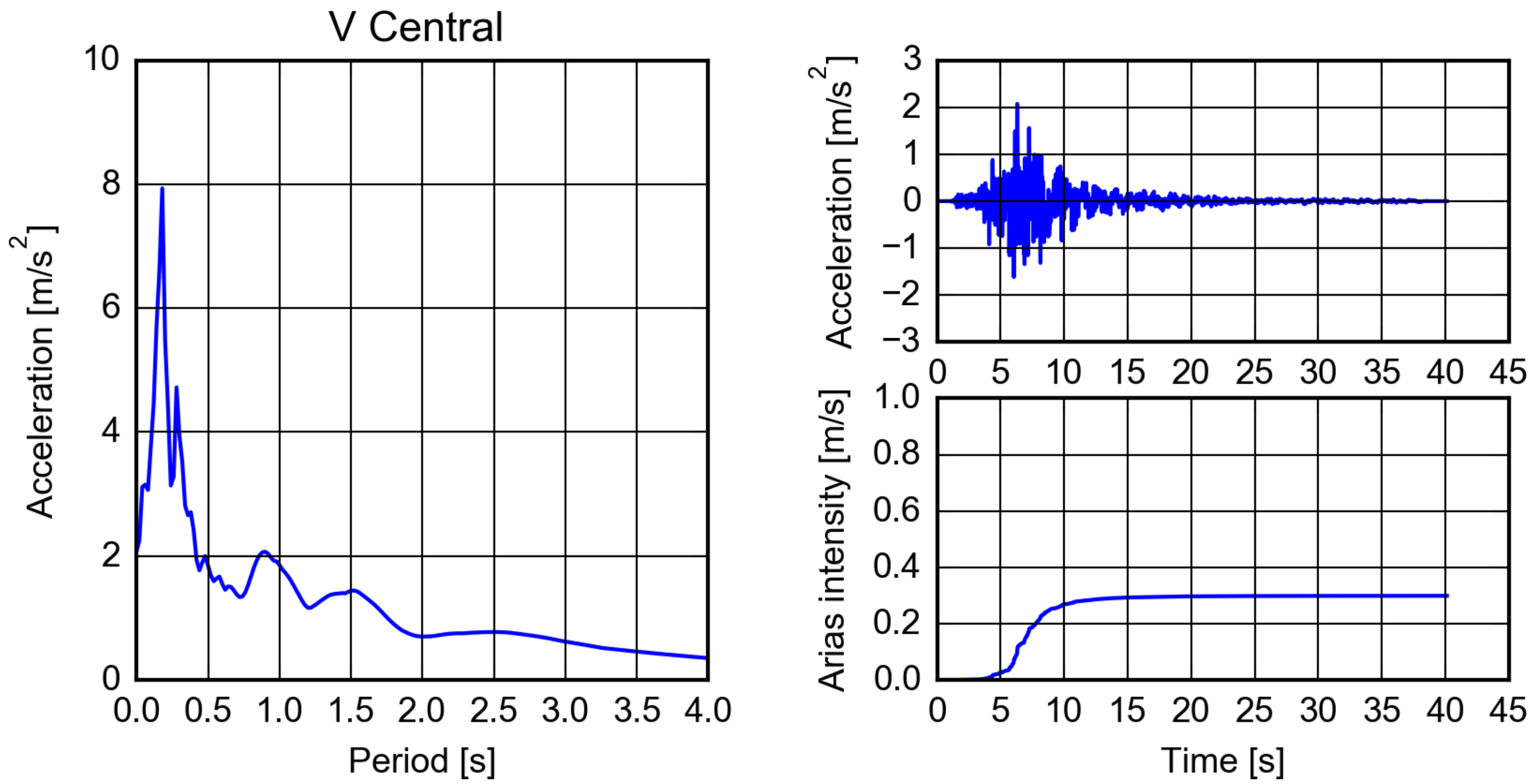
Seismic input

- **Analysis of the seismic input (**PGA, Duration, Arias Intensity)



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Seismic input

➢ **Analysis of the seismic input (**PGA, Duration, Arias Intensity)

Seismic input	Arias intensity [m/s]	PGA [g]	Duration [s]
Central V	0.30	0.21	40.13
Central H1	0.41	0.26	40.13
Central H2	0.41	0.19	40.13
Friuli V	0.18	0.20	36.39
Friuli H1	0.69	0.24	36.39
Friuli H2	0.45	0.26	36.39

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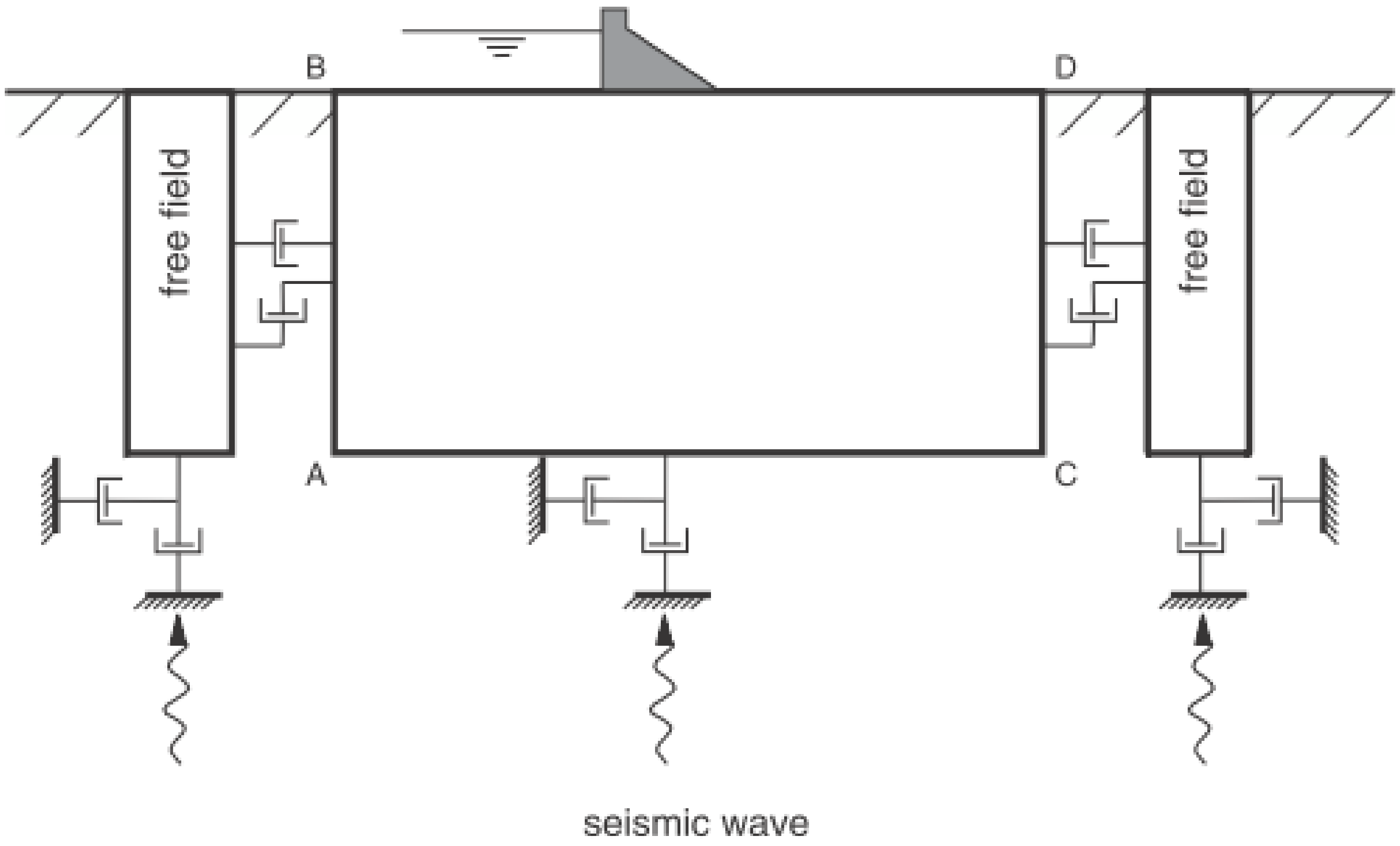
Seismic input

➢ Boundary conditions for dynamic simulation



Stress input

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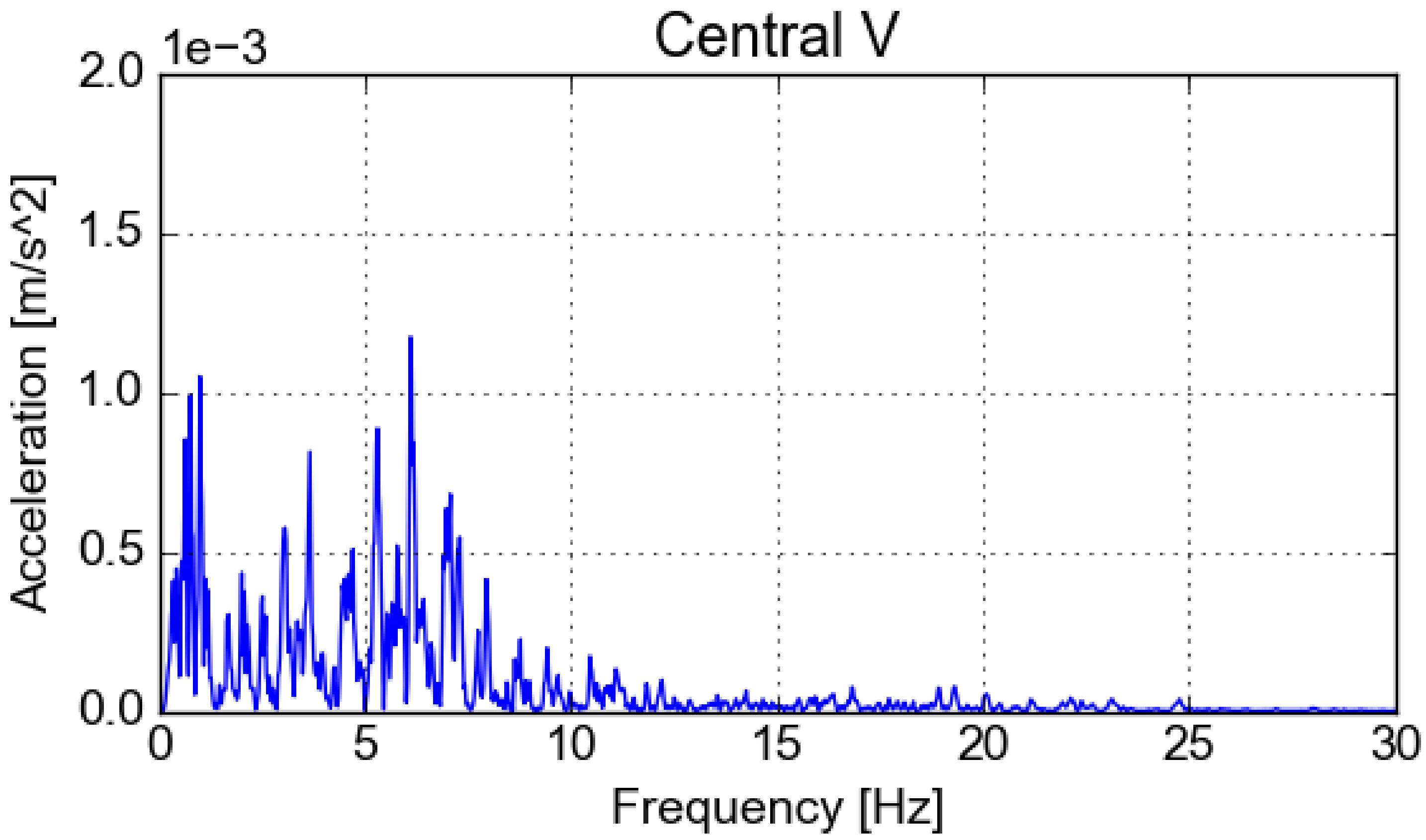
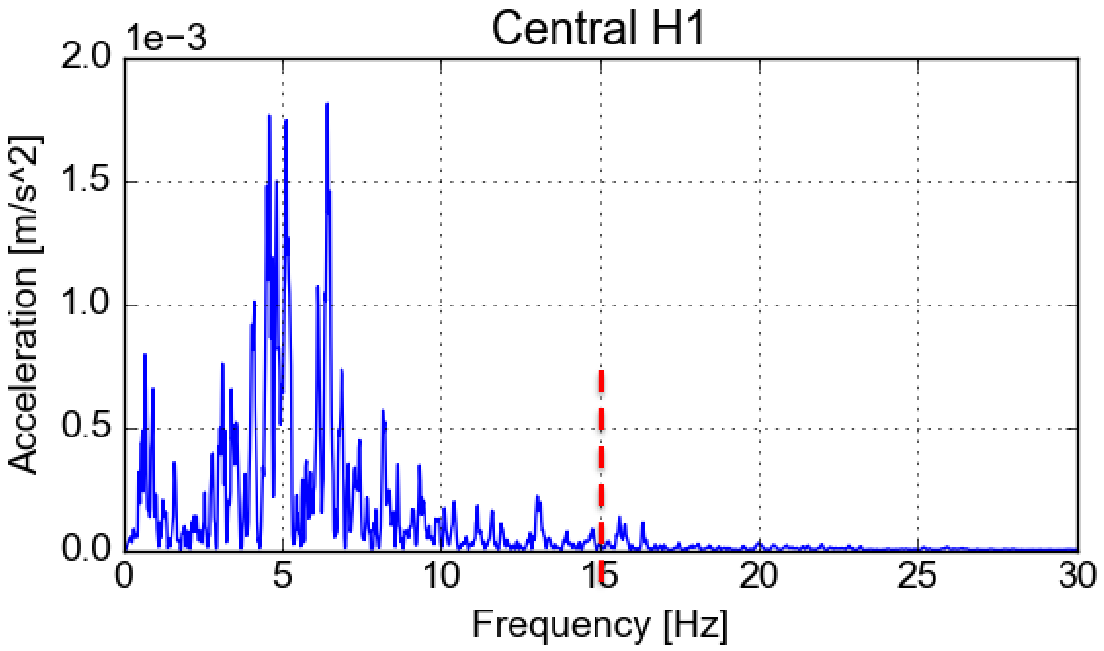
Seismic input

➢ **Frequency content** by FFT



Seismic input

- **Mesh design** to ensure correct wave transmission during dynamic analysis



$$\Delta l \leq \frac{\lambda}{10}$$ Mesh elements size

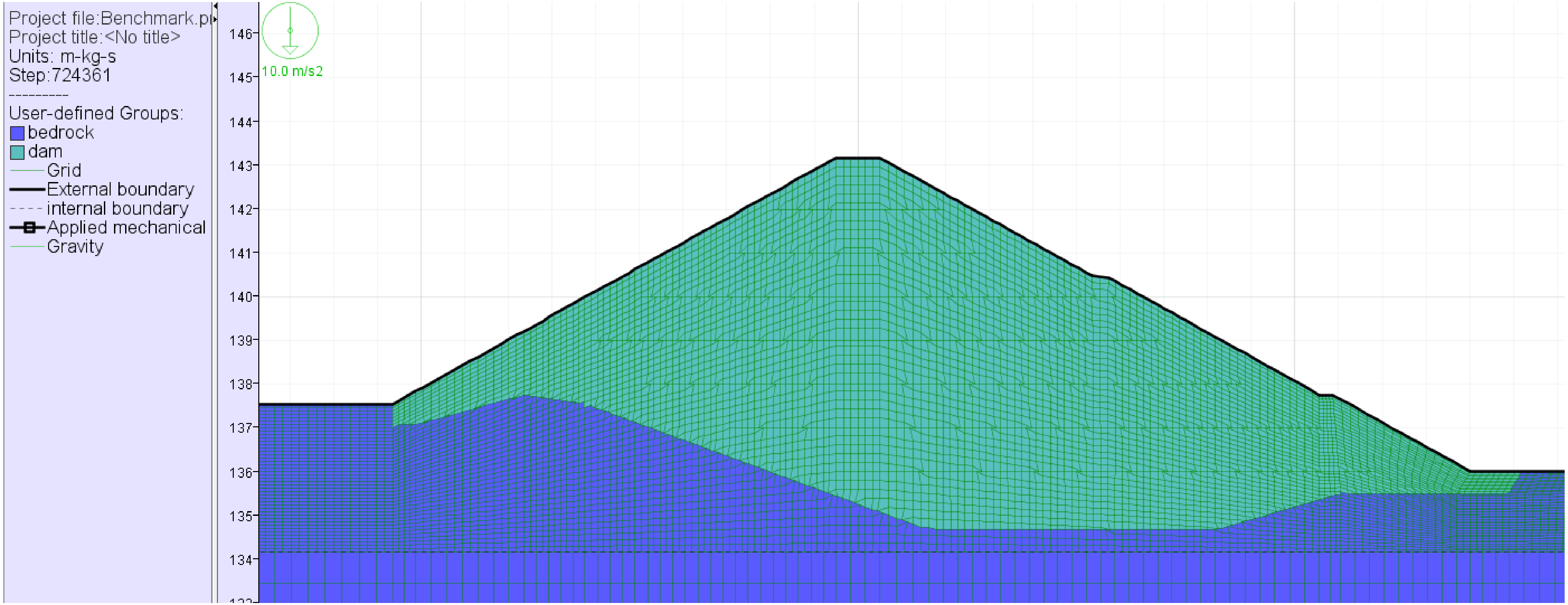
$$\lambda = Vs_{min}/f_{c,max}$$ Wavelength

$$V_{s,min} \sim 400\ m/s$$

$$\boxed{f_{c,max} = 15\ Hz}$$

$$\Delta l \leq 2.5\ m$$

Mesh



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Rockfill Constitutive model

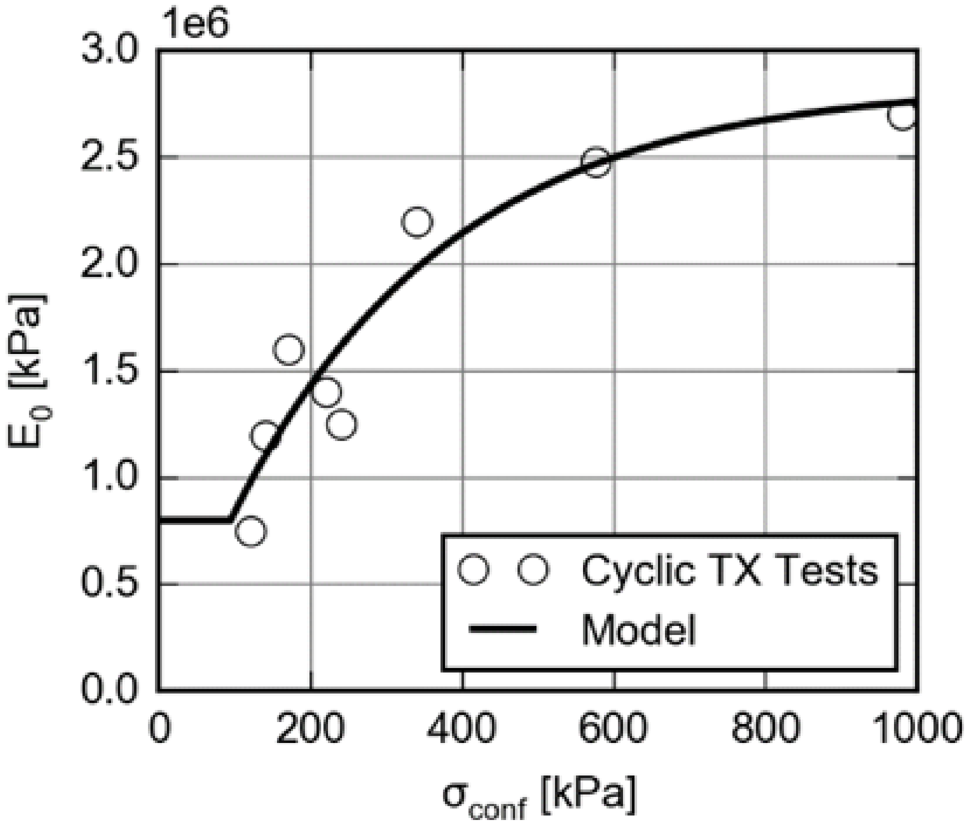
Constitutive model: Nonlinear elastic (modulus depend on local confinement), Mohr-Coulomb plasticity

DYNAMIC INITIAL MODULUS

$$E_0 = E_{ref} \cdot \left(1 - e^{-a \cdot \frac{\sigma_{conf}}{p_{atm}}}\right) > 800\ MPa$$

STATIC MODULUS

$$E = 0.1 \cdot E_0$$



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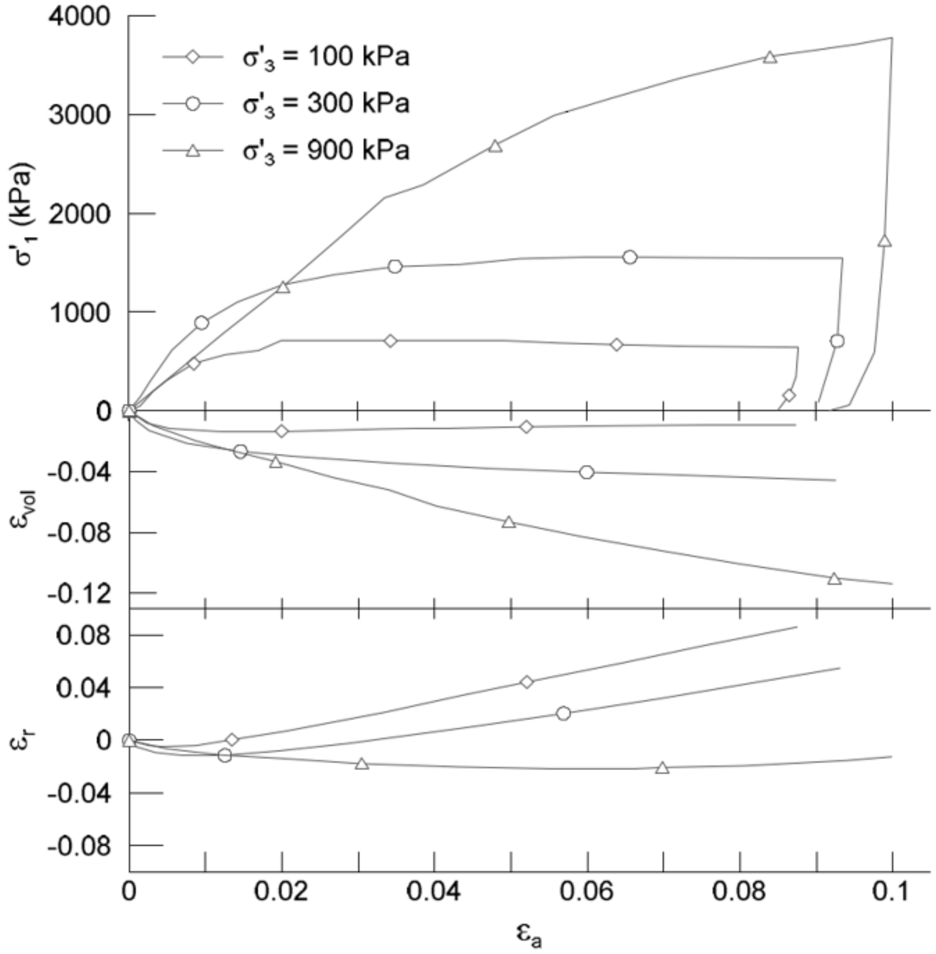

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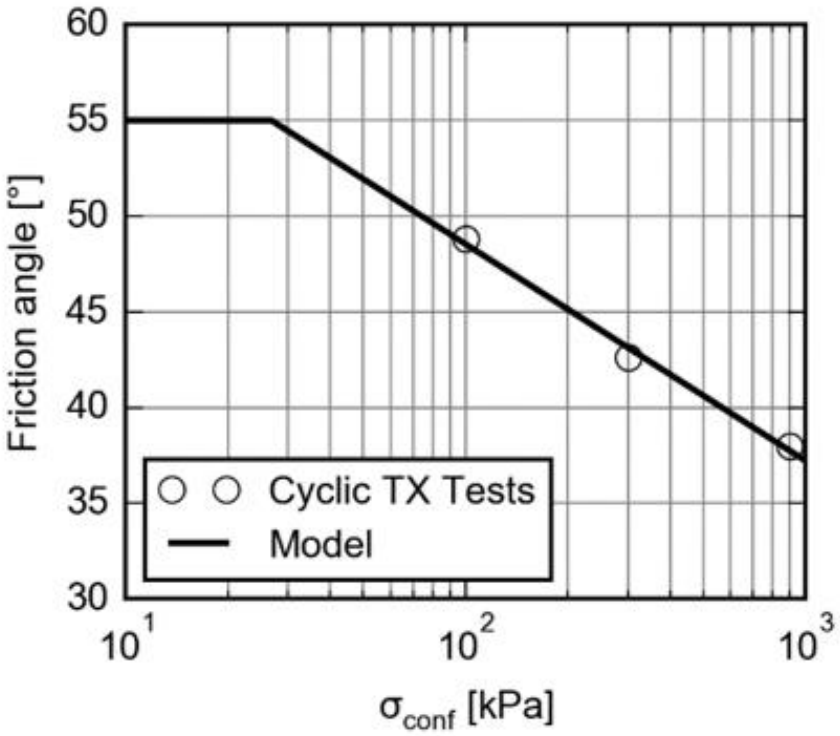

$$\phi = \Delta\phi \cdot \log(\sigma_{conf}) + \phi_0 < 55°$$

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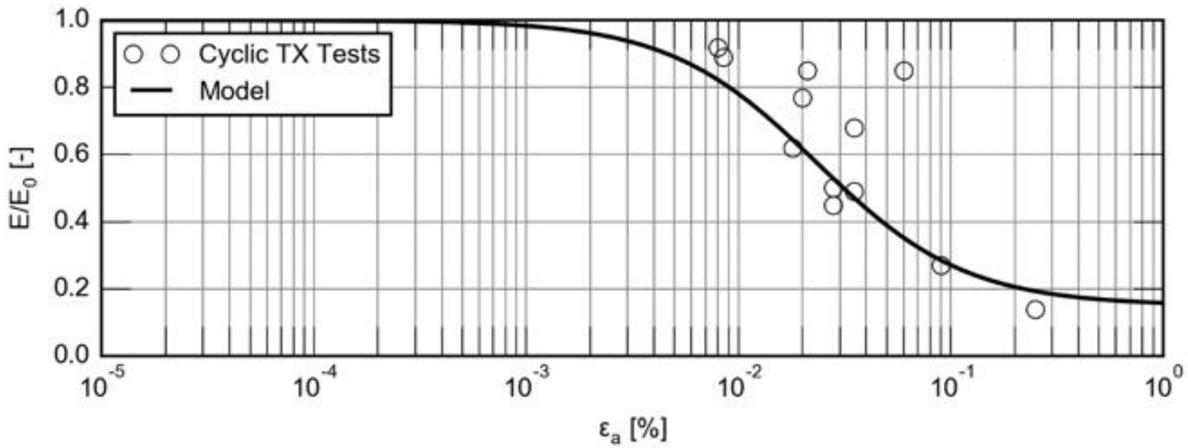
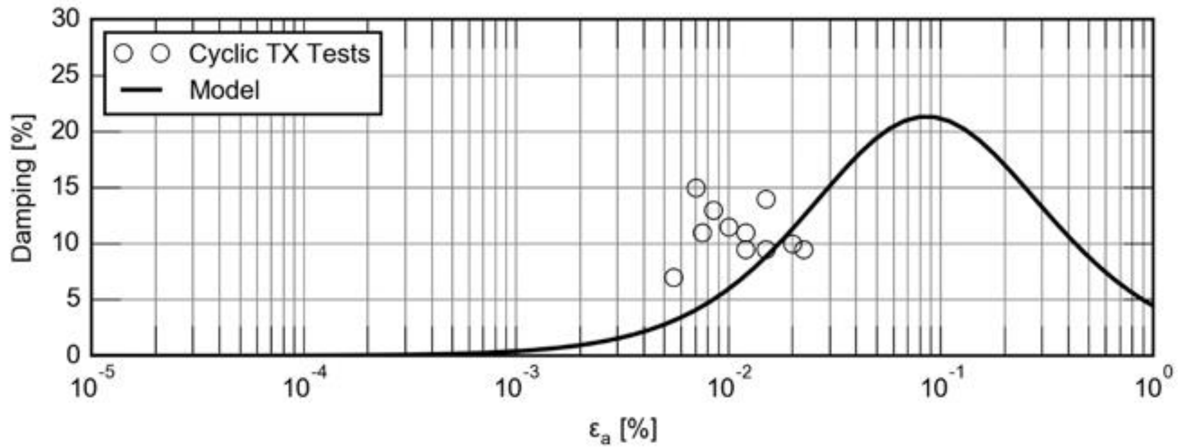
Rockfill Constitutive model

Constitutive model: Hysteretic damping





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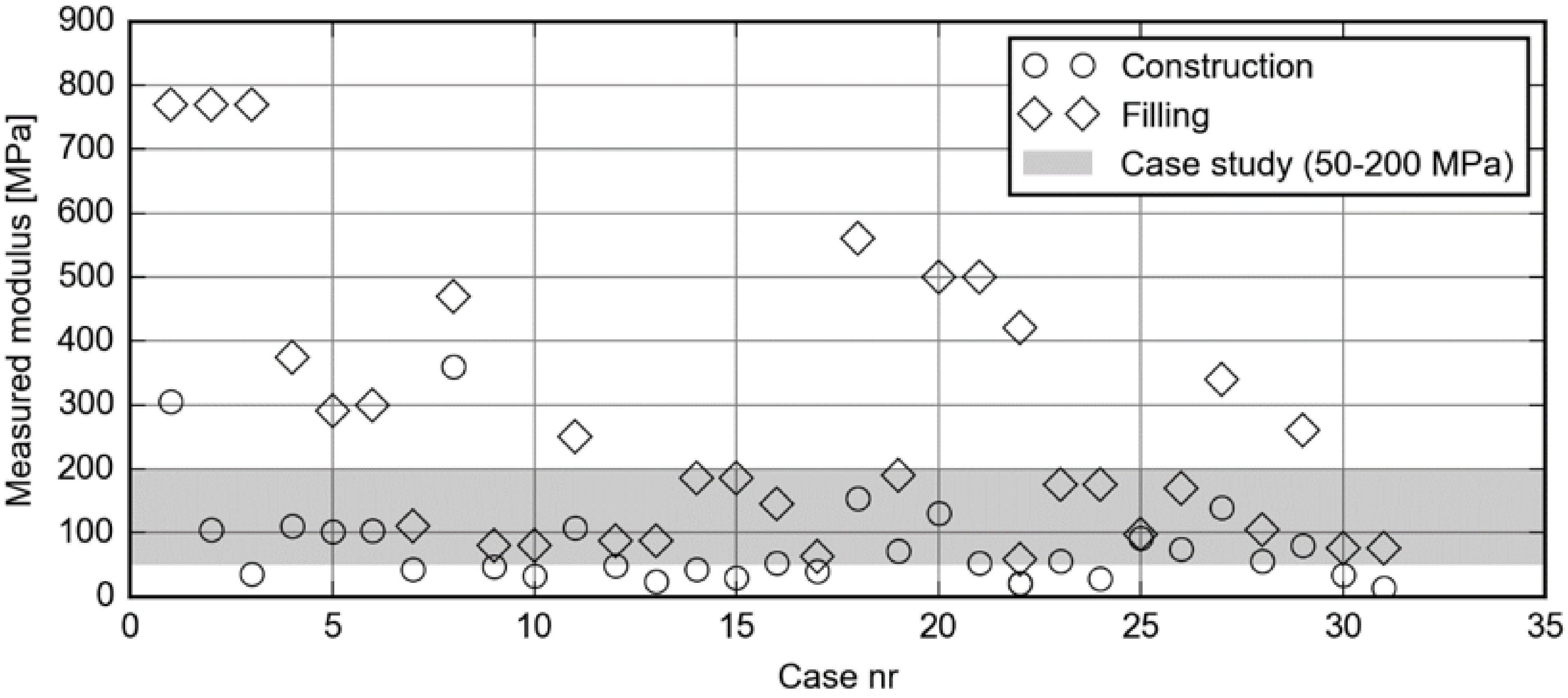
Rockfill Constitutive model

Literature review



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Performed analyses

- **Static analysis**
  - Simulation of dam construction phasing (layered construction, 10 steps simulated) with update of mechanical properties at each phase
  - Reservoir filling in six steps

- **Dynamic analysis**
  - Time history analysis based on explicit **finite-difference** scheme
  - Estimation of the **natural frequency** of the dam (dynamic analysis in **elastic conditions**)
  - Hydrodynamic effects are neglected

FLAC software by Itasca Consulting Group has been used for simulations

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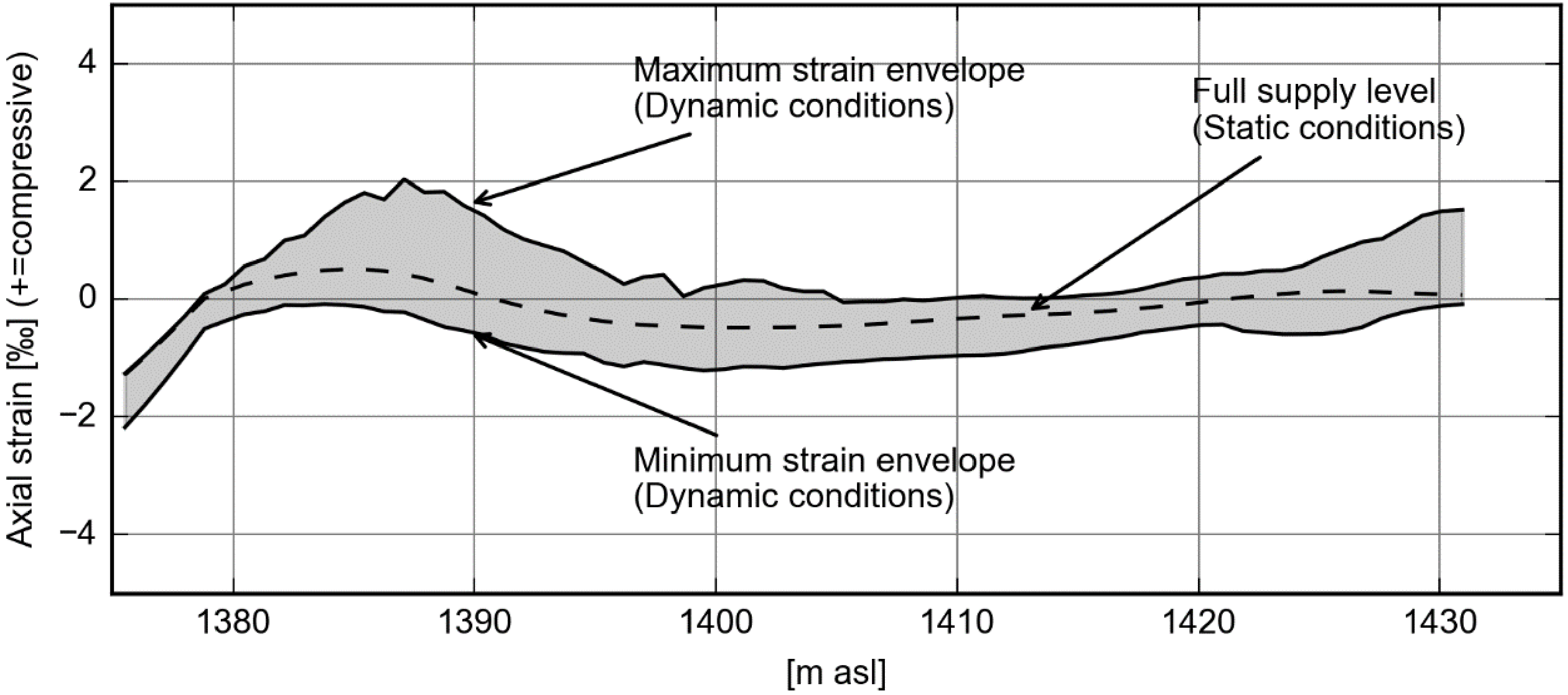
Model for the bituminous concrete facing

- Asphalt facing modelled as a membrane glued to the upstream slope
- Low elastic modulus (E = 10MPa) and small thickness of 0.01 cm
- Conservative analysis letting the asphalt deform like a glued membrane not resisting to bending moments.

Model for the bituminous concrete facing



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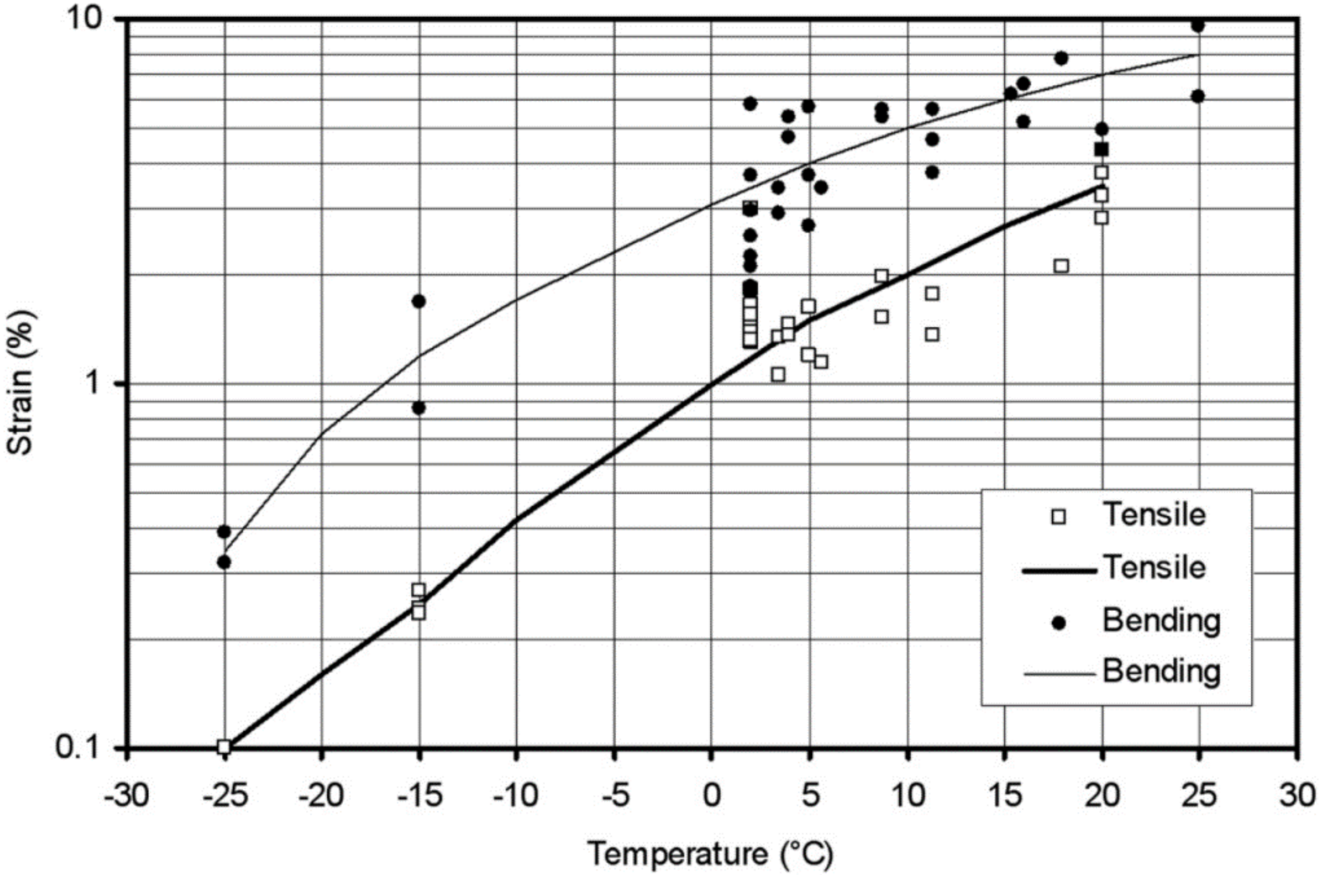
Model for the bituminous concrete facing

Maximum allowable tensile strain as function of temperature



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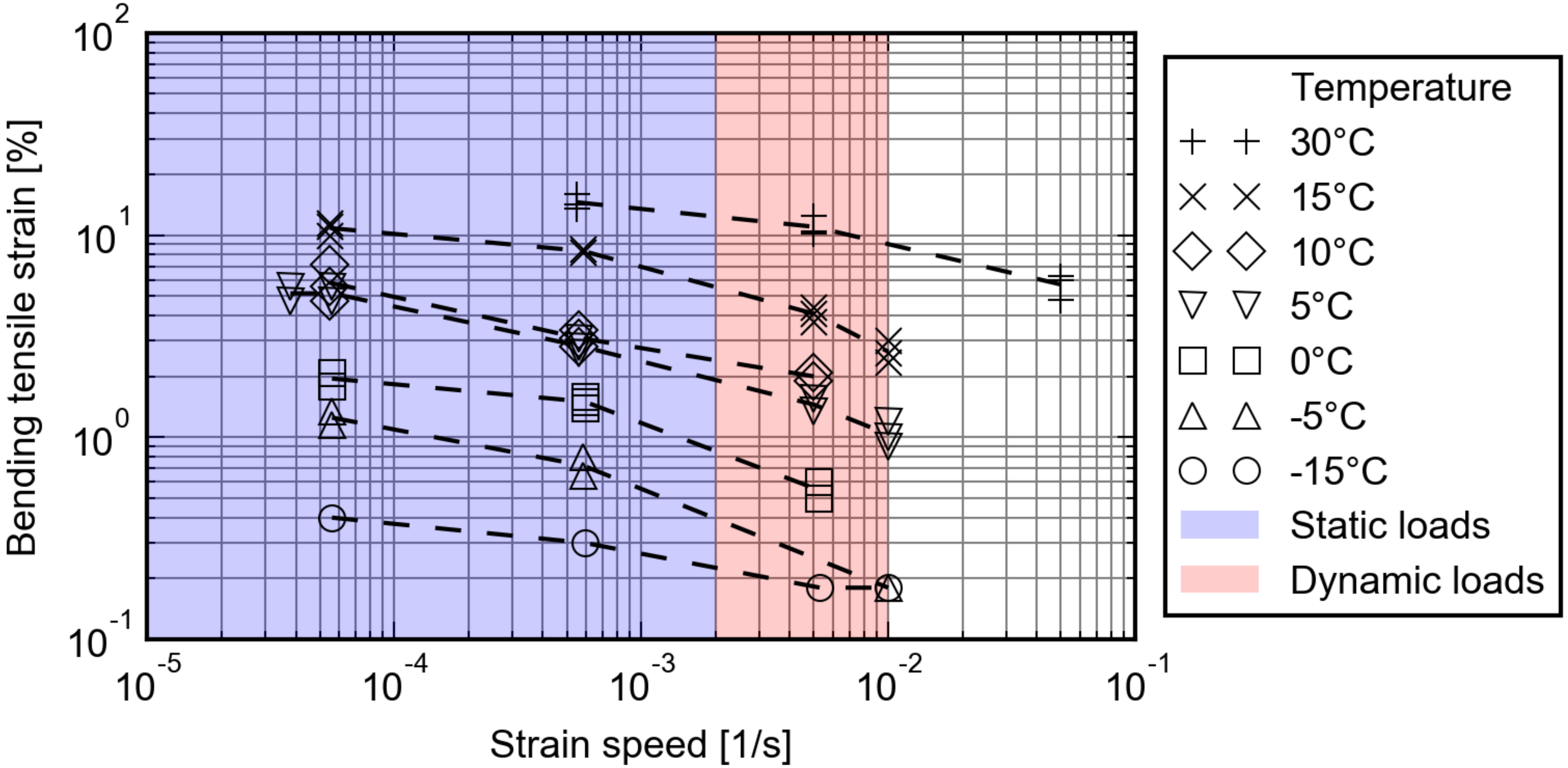
Model for the bituminous concrete facing

Strain rate influence on maximum allowable tensile strain



General comments and final remarks

- Direct correlation between Arias Intensity and permanent displacements
- Permanent displacements induced by the earthquake in the order of few centimetres
- Low value of the PGA, which corresponds to a return period of about 600 years according to the location of the dam
- The obtained maximum tensile strain is below the asphalt yield strain even for high strain rates under low temperatures

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