COMSOL CONFERENCE 2017 ROTTERDAM

UNIVERSITÀ DI PISA

Frequency response analysis of soil-structure interaction for concrete gravity dams

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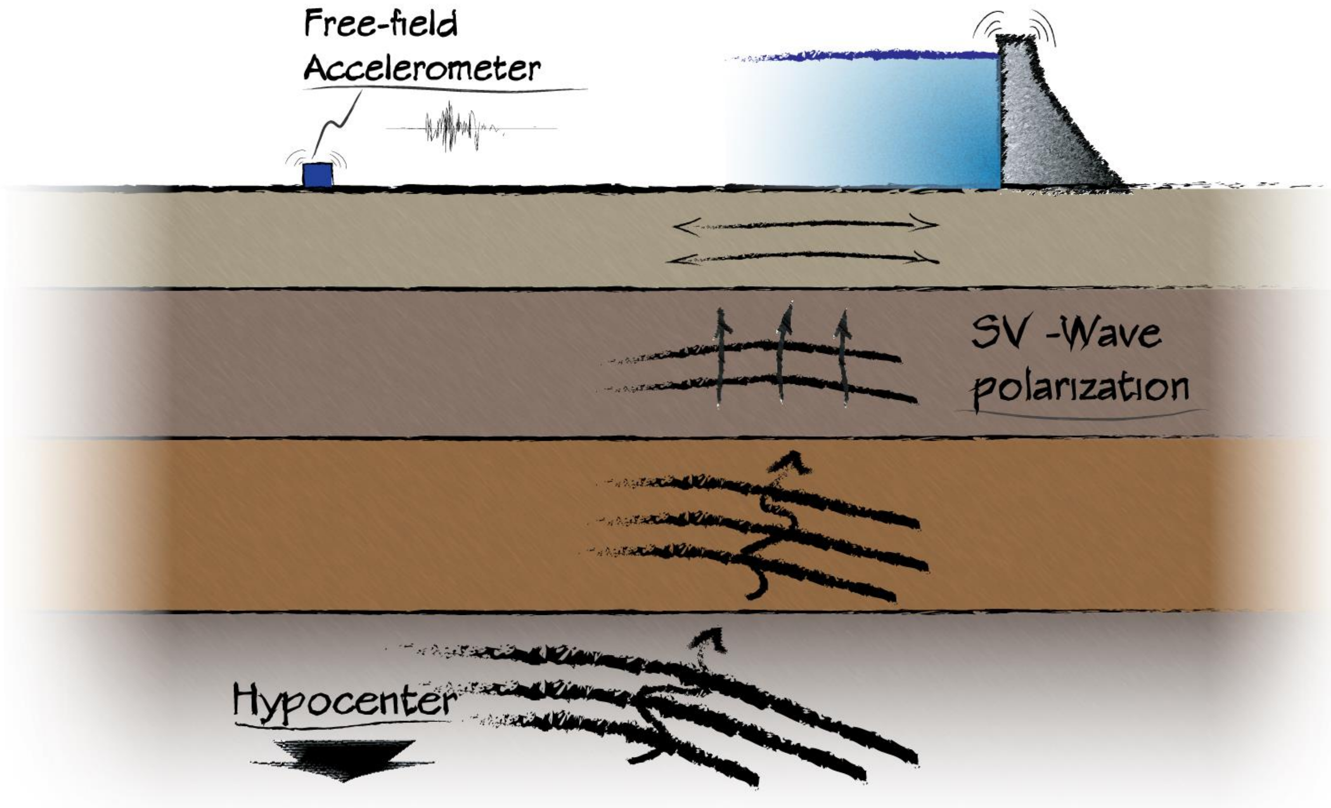
Seismic assessment of gravity dams

- Italy has over 500 large concrete dams
- Complex phenomenon
  - Fluid coupling
  - Wave mechanics
  - Nonlinear material behaviour
- Specific ncessities:
  - Assessment of code requirements compliance
  - Performing or relatively fast analyses on many structures
  - Reasonable accuracy within uncertainty ranges

Seismic waves

- Actual earthquake condition:



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Soil structure interaction - SSI

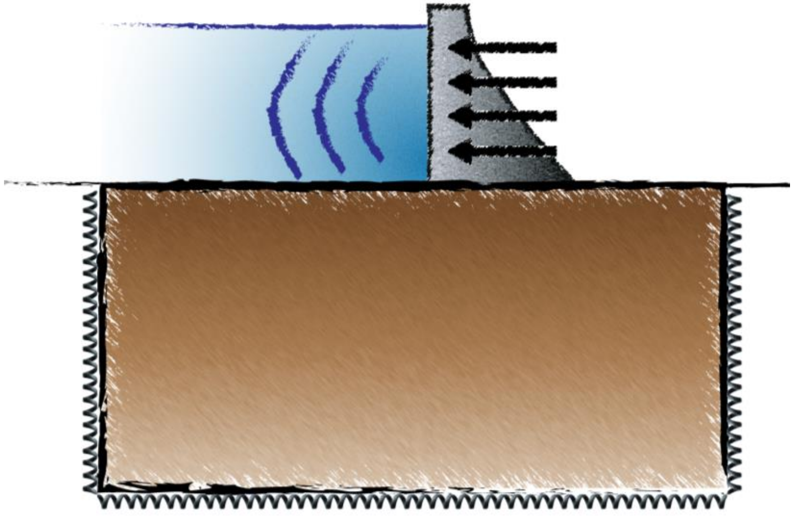
- Effects of soil deformation on structural response:
  - Seismic SSI: [Clough & Penzien]:
    - **Kinematic interaction**: Influence of structure stiffness on earthquake excitation
    - **Inertial interaction**: Influence of structure mass on earthquake excitation
- Consequences:
  - **Lengthening of natural periods** due to the **added foundation flexibility**
  - **Radiation damping**: Additional dissipation of energy via wave reflection in the **unbounded half-space.**

System modeling

Traditional method:

Massless terrain [Wilson]:

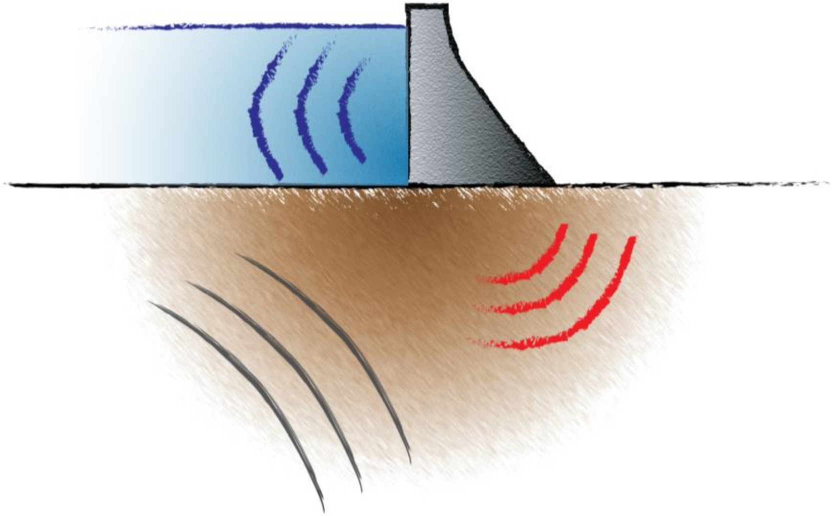
- Null terrain density
- Body load on the structure
- Fixed constraint at the bottom of bounded soil



Proposed method:

Full analysis:

- Real terrain density
- No load on the structure
- Unbounded half space terrain with incoming wavefront

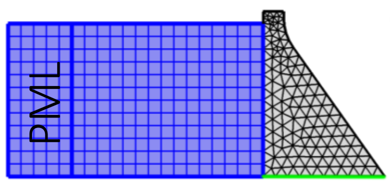


COMSOL implementation

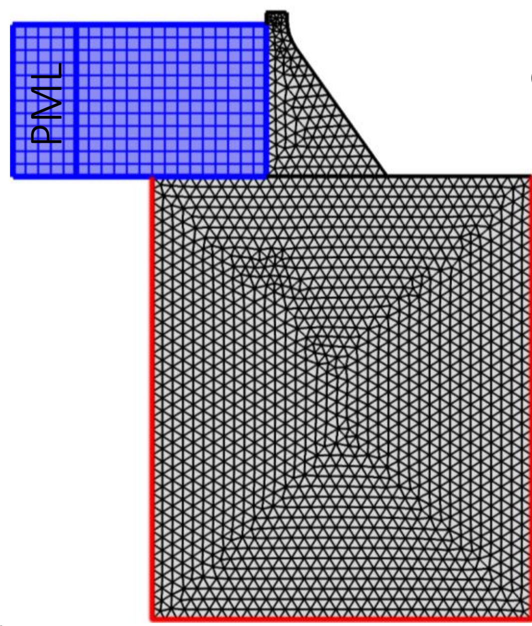
Modeling strategy:

- Frequency domain analysis – linear system behaviour
- Solid mechanics interface & Acoustics interface
- Use of Perfectly Matched Layers (PML)

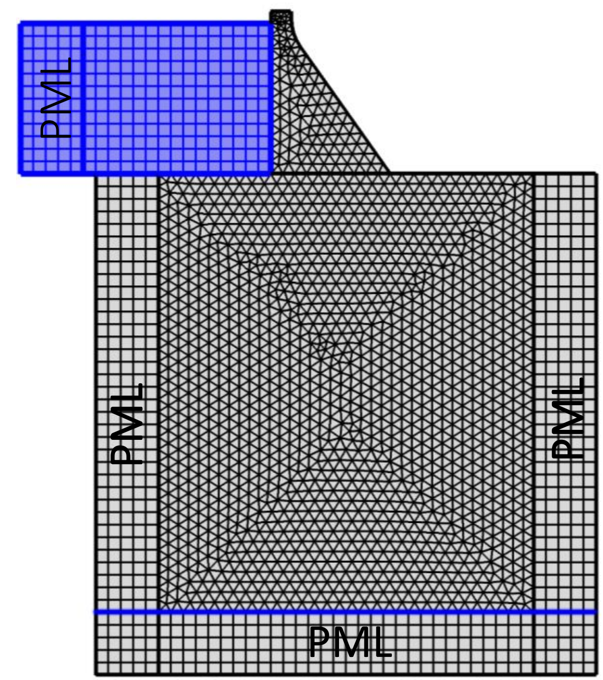
a)



b)



c)



THREE MODELS:

a) RIGID BASE

b) MASSLESS

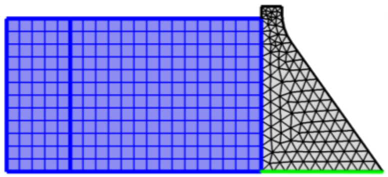
c) PML

Reservoir modeling:

- Added masses
- Structural-acoustic coupling

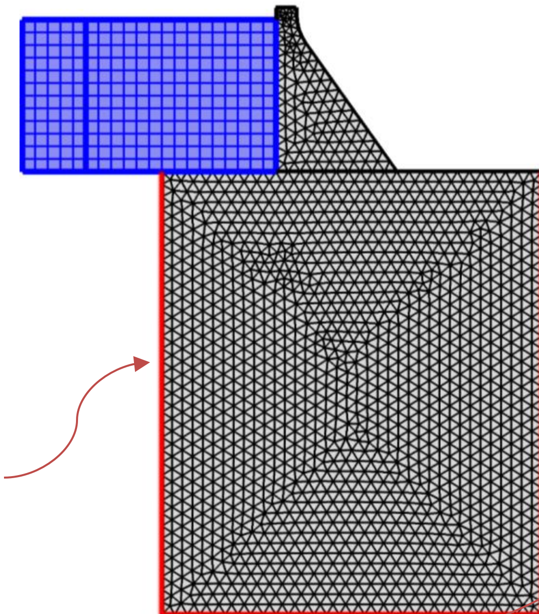
Boundary conditions

a)



$$\begin{cases} \ddot{u} = \omega^2 u = 1 \\ \ddot{v} = 0 \end{cases}$$

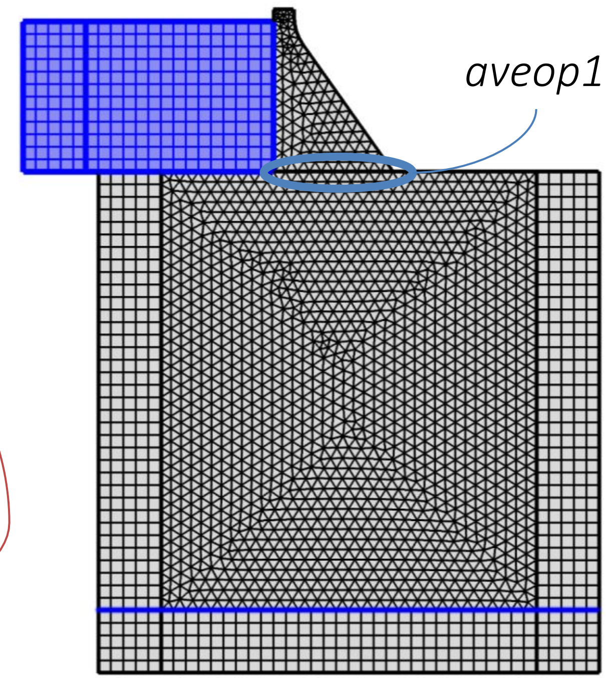
b)



Prescribed acceleration $\ddot{u} = \omega^2 u = 1$

$$\begin{cases} \ddot{u} = \omega^2 u = 1 \\ \ddot{v} = 0 \end{cases}$$

c)



Line Load – auxiliary variable:

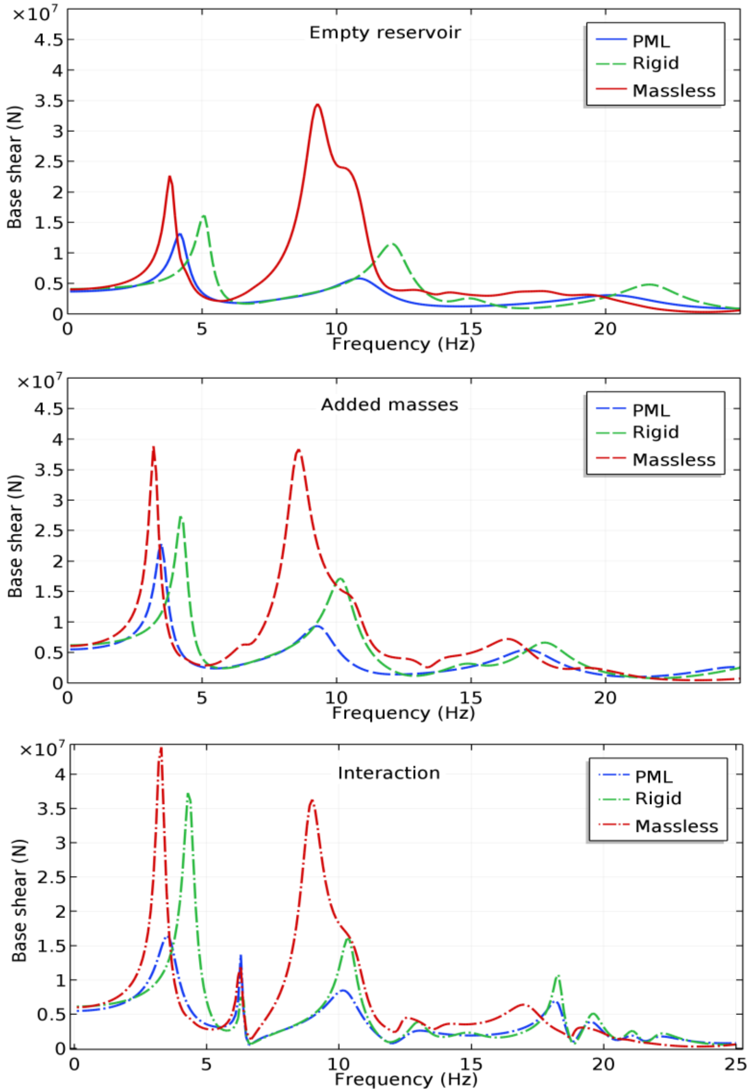
$$q = \text{para}$$

+ Global equation:

$$aveop1(solid.accX) - 1 = 0$$

	Concrete	Foundation rock
Density ρ (kg/m³)	2518	2300
Young modulus E (MPa)	20559	21961
Poisson modulus ν	0.1761	0.2000
Damping coefficient ξ	0.05	0.05

Results: Base shear



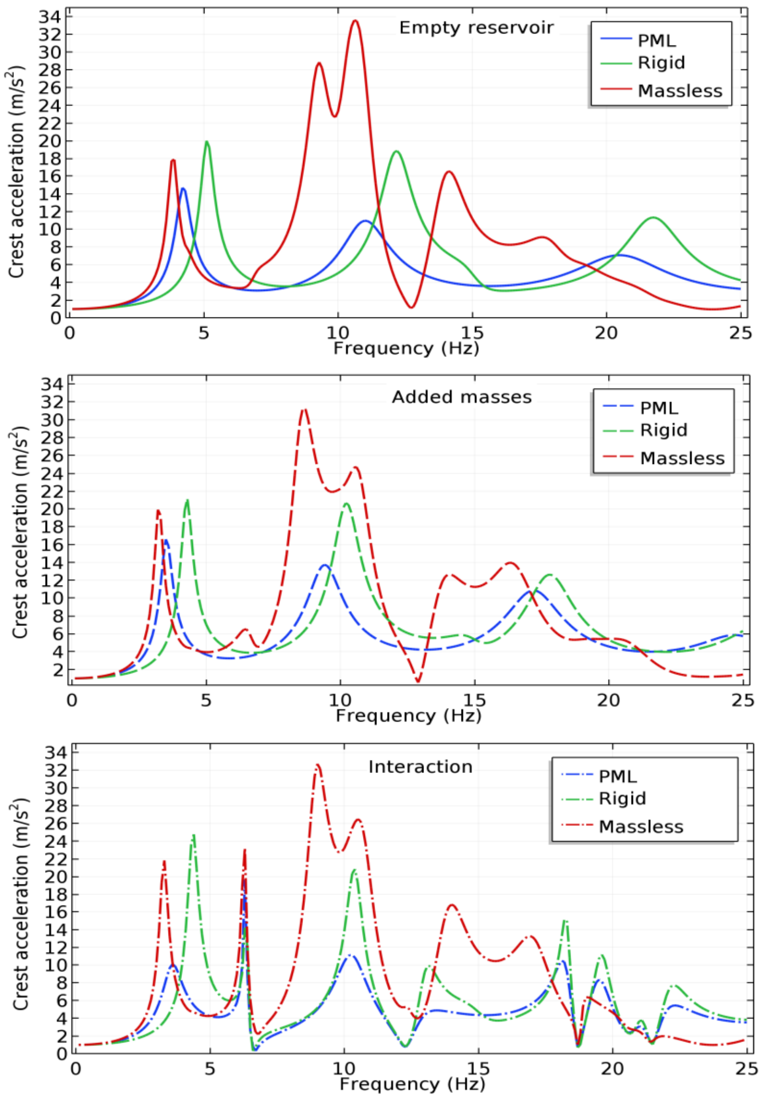
Massless model:

- Peak frequency shift
- Amplified peak value
- Spurious second large peak

Unbounded model:

- Peak frequency shift
- Reduced peak value
- No spurious peaks

Results: Crest acceleration



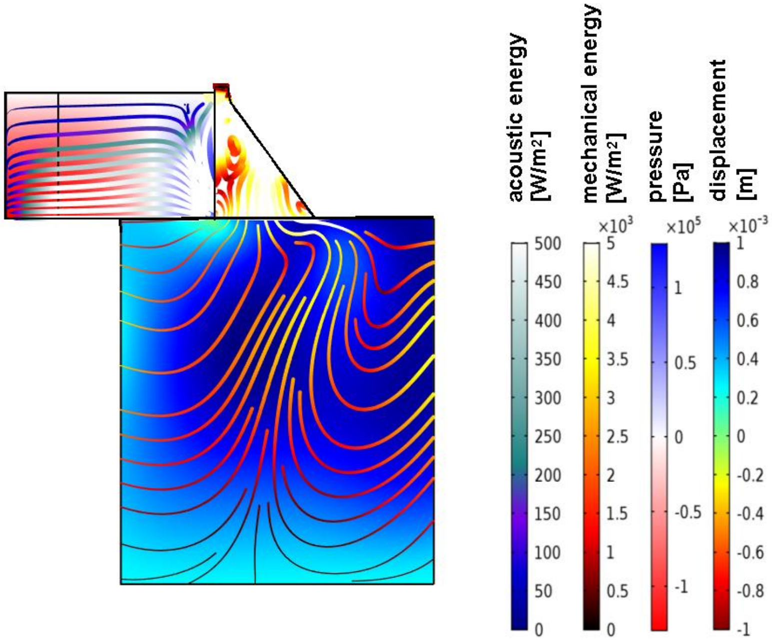
Massless model:

- Peak frequency shift
- Incorrect peak value
- Spurious second large peak

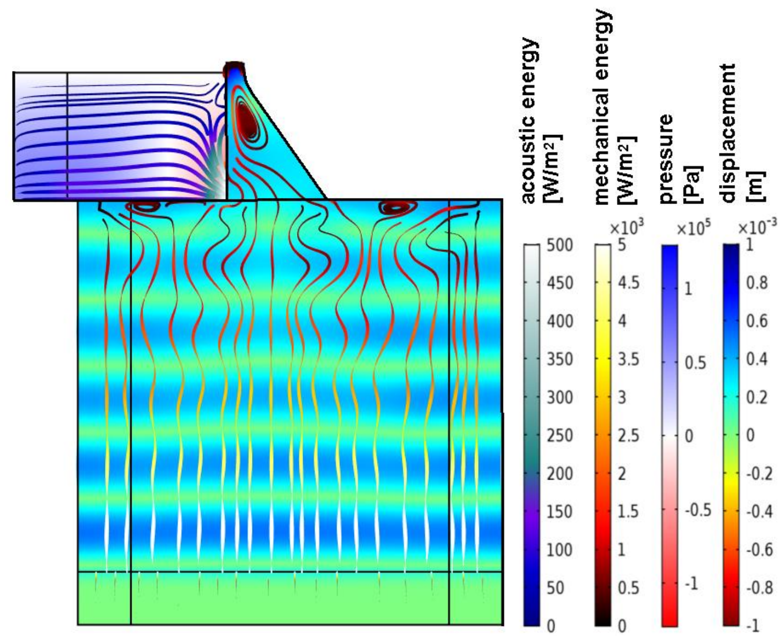
Unbounded model:

- Peak frequency shift
- Reduced peak value
- No spurious peaks

Stress and energy



Massless model



Unbounded model

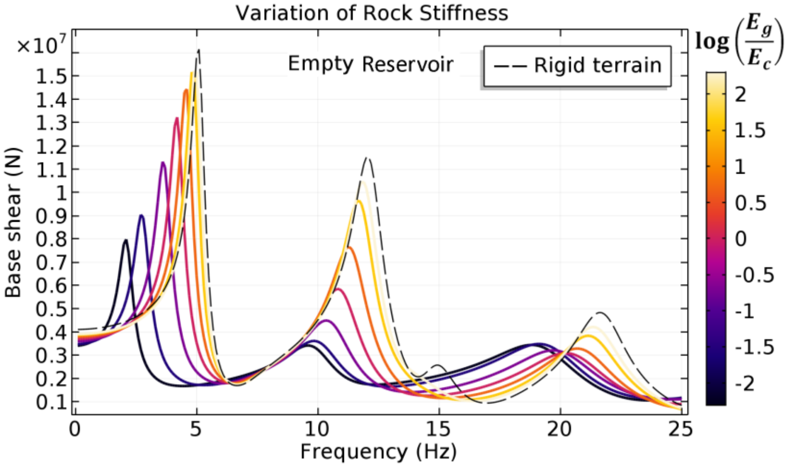
25 Hertz excitation case

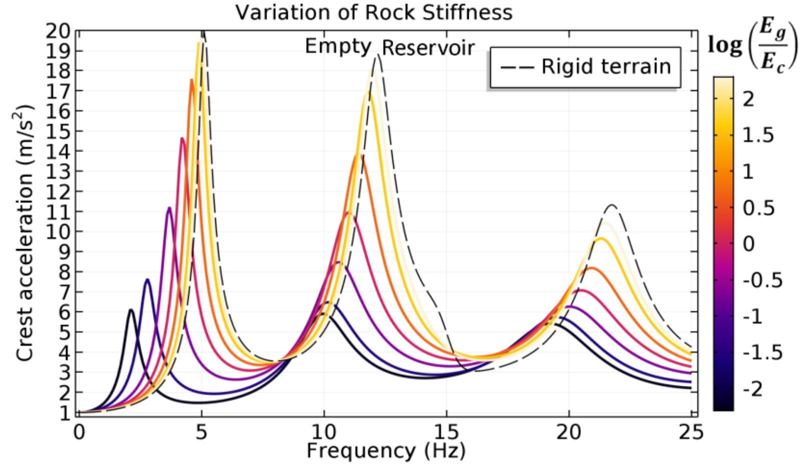
Mechanical energy flux $I_i = \sigma_{ij} \cdot v_j$

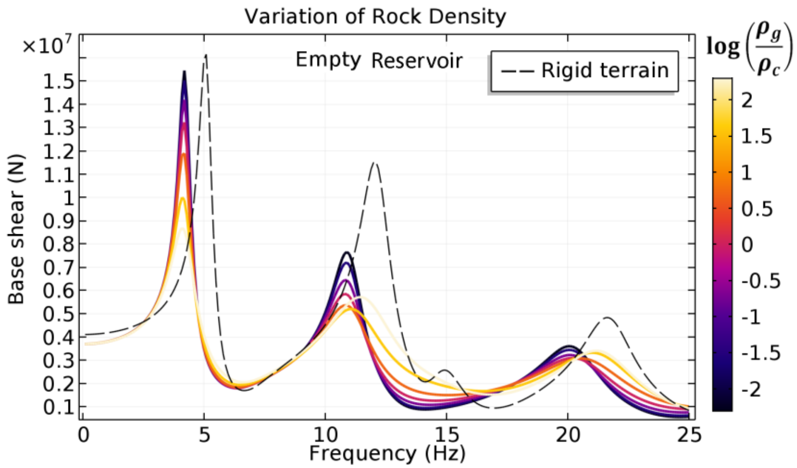
Parametric study

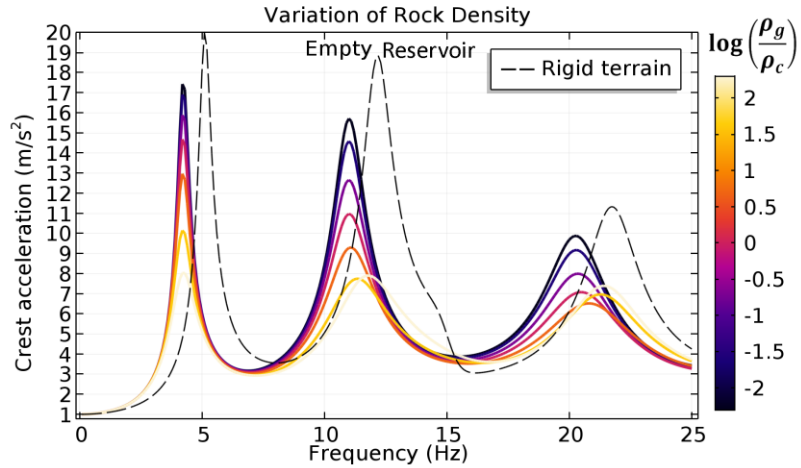
- Variation of results with four parameters:
  - Concrete density ρ_c
  - Concrete stiffness E_c
  - Rock density ρ_g
  - Rock stiffness E_g

Parametric study – empty reservoir

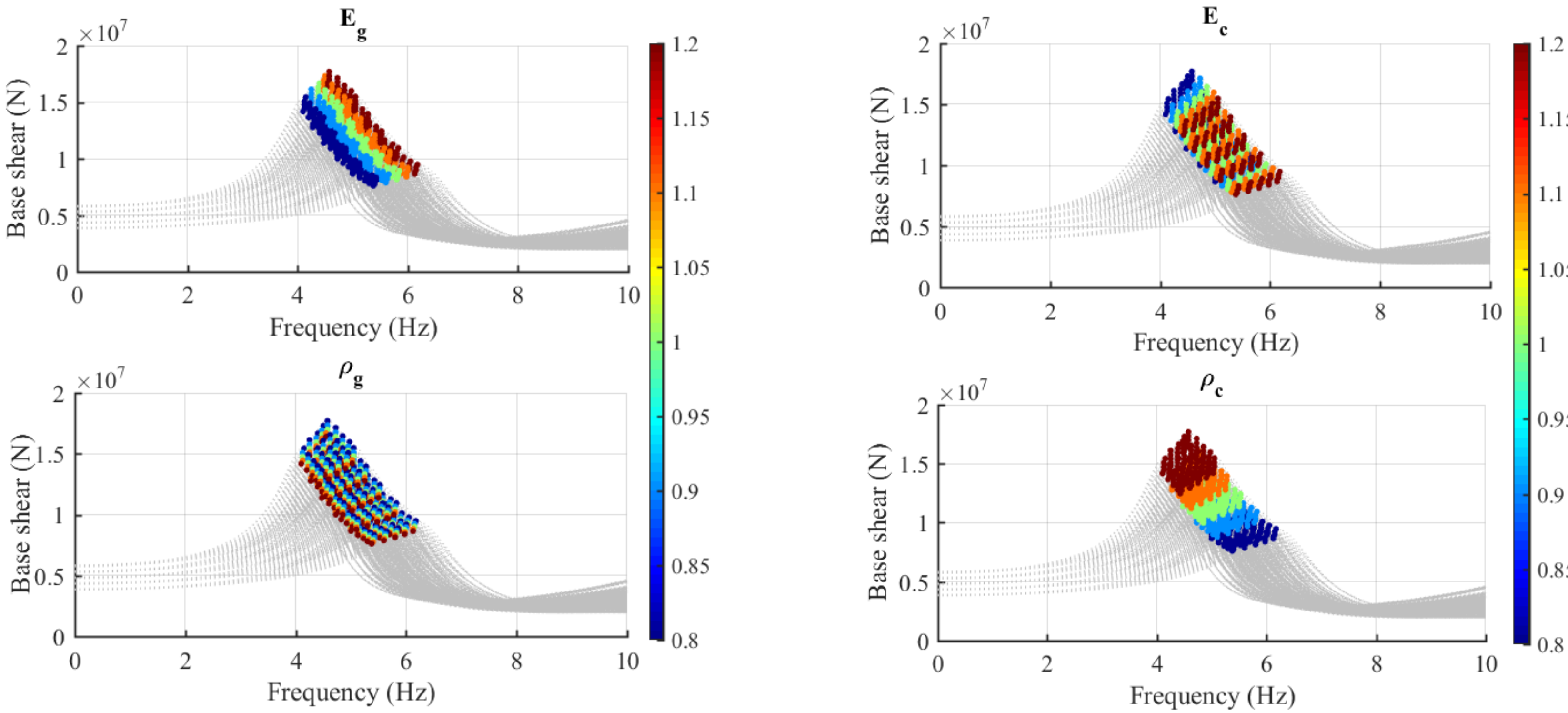








Parametric study - empty reservoir



Rock properties:

- Stiffness
- Density

Concrete properties:

- Stiffness
- Density

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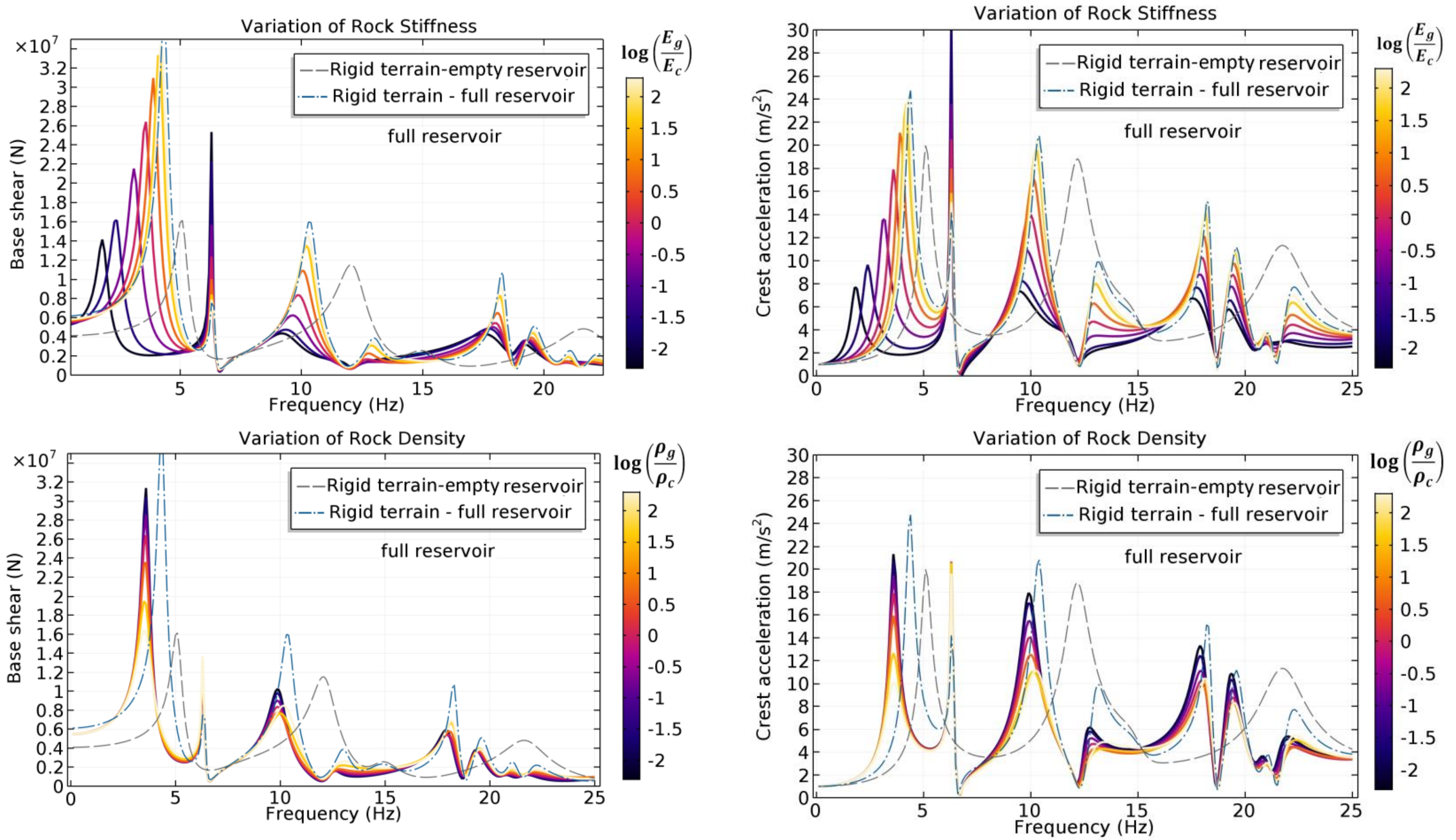
Parametric study – full resevoir



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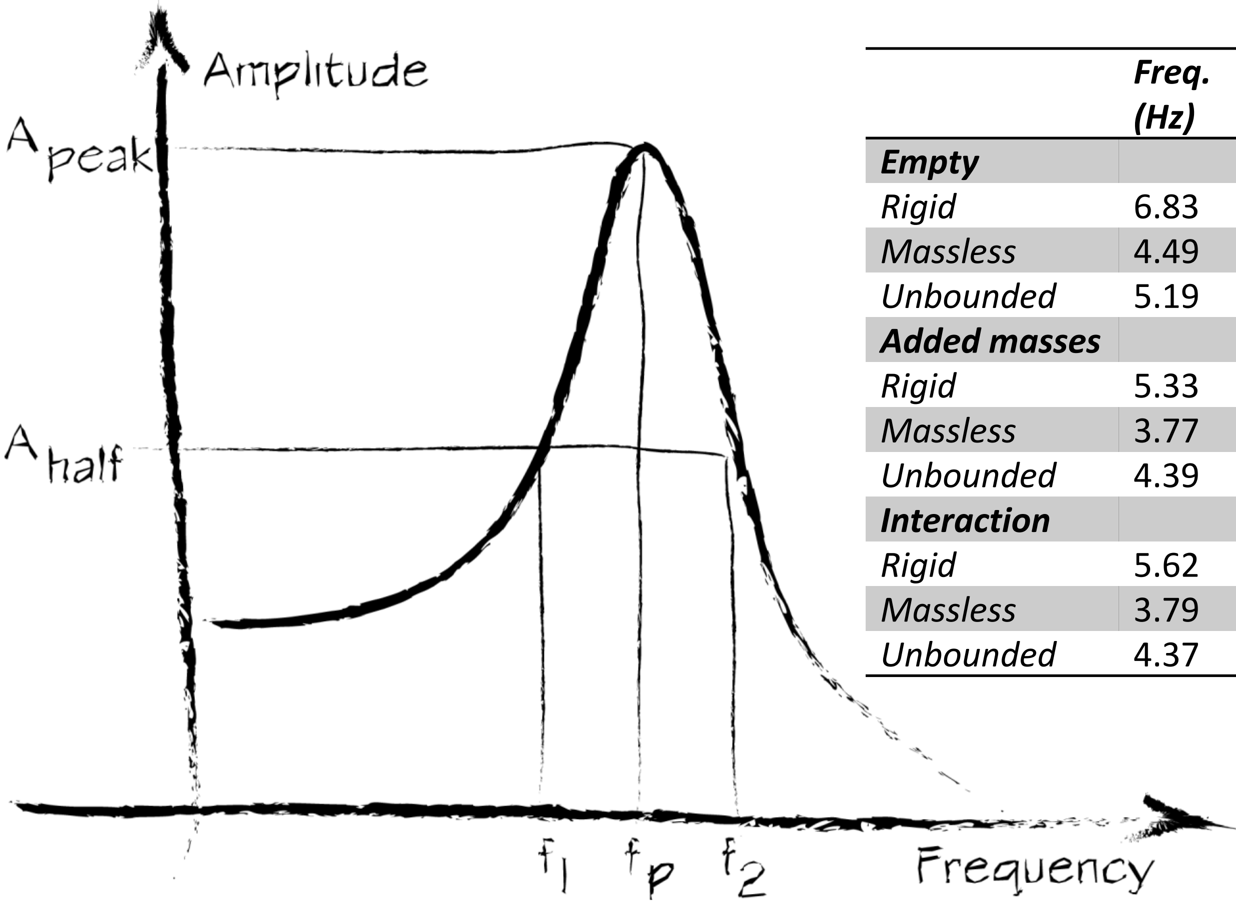
Equivalent radiation damping

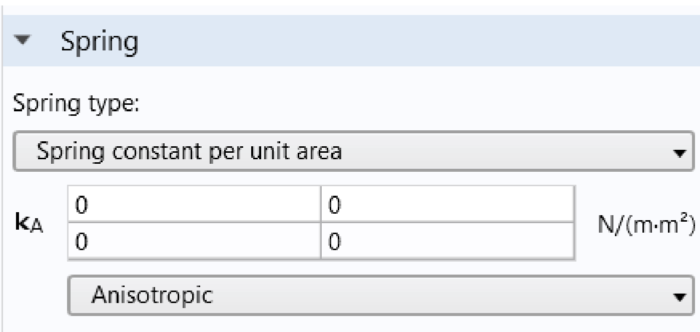
Half-power banwidth method, damping ratio: $\eta = \dfrac{\mathrm{f}_2 - f_1}{\mathrm{f_p}} \cong 2\xi$



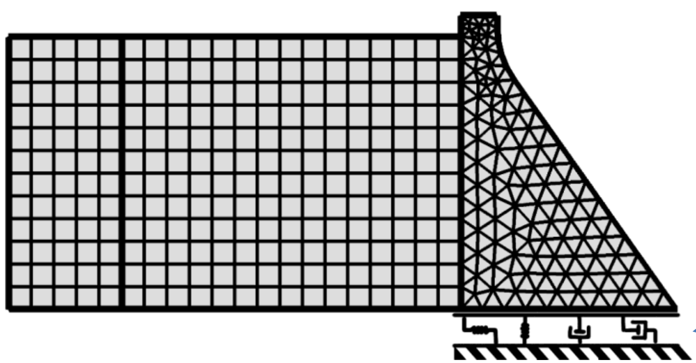
	Freq. (Hz)	Loss factor η	Equivalent damping ξ	Peak shear (N) x10^7
Empty				
Rigid	6.83	9.78%	4.89%	2.336
Massless	4.49	10.94%	5.47%	2.887
Unbounded	5.19	23.11%	11.56%	0.870
Added masses				
Rigid	5.33	4.95%	2.48%	3.597
Massless	3.77	8.18%	4.09%	4.761
Unbounded	4.39	13.77%	6.89%	2.274
Interaction				
Rigid	5.62	9.47%	4.74%	6.639
Massless	3.79	9.04%	4.52%	5.490
Unbounded	4.37	17.23%	8.62%	2.871

Simplified equivalent model

Match the complete model with «ordinary» boundary conditions:



Spring – Dashpot base:
COMSOL Functionality - Thin Elastic layer: k_1, k_2, c_1, c_2



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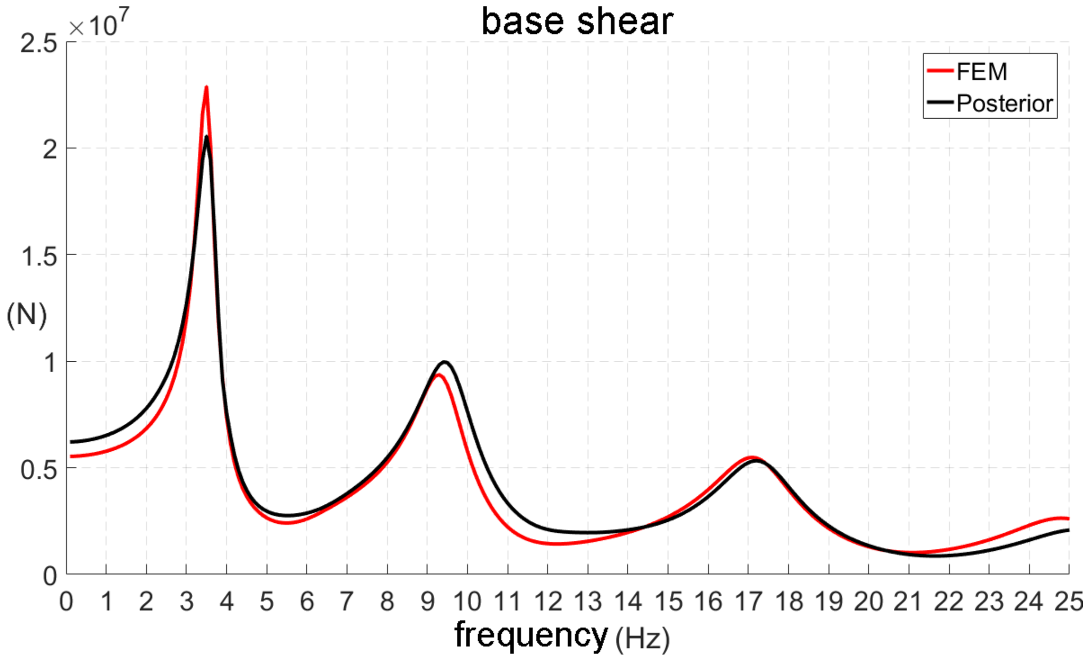
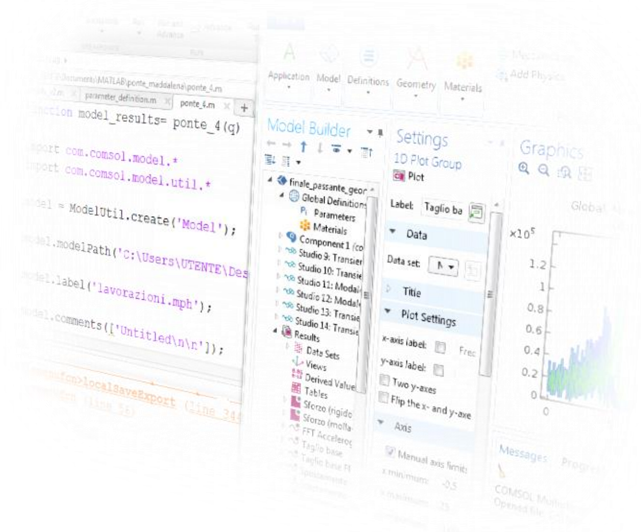
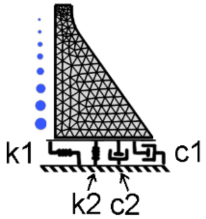
Simplified equivalent model



LiveLink functionality For MATLAB:



Parameter	[N/sqm]	[N·s/sqm]
k_1	8.6e+9 ± 1.1e+9	
k_2	9.7e+8 ± 9.3e+7	
c_1		3.6e+7 ± 2.3e+6
c_2		1.5e+7 ± 6.8e+6



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Conclusions

Comparison of different models:

- Effects of half-space modeling
- Radiation damping phenomenon quantification
- Evaluation of equivalent systems to be implemented in advanced analyses including nonlinearity
- Definition of equivalent damping to adopted in code-defined response spectra

Further developments:
- Extension to 3D
- Implementation of nonlinear material models
- Accelerogram deconvolution