Seismic Fluid-Structure Interaction of Concrete Gravity Dams: A Numerical Approach in FEA NX

Harsha Tadavarthi | Geotechnical Team Leader & Technical Manager

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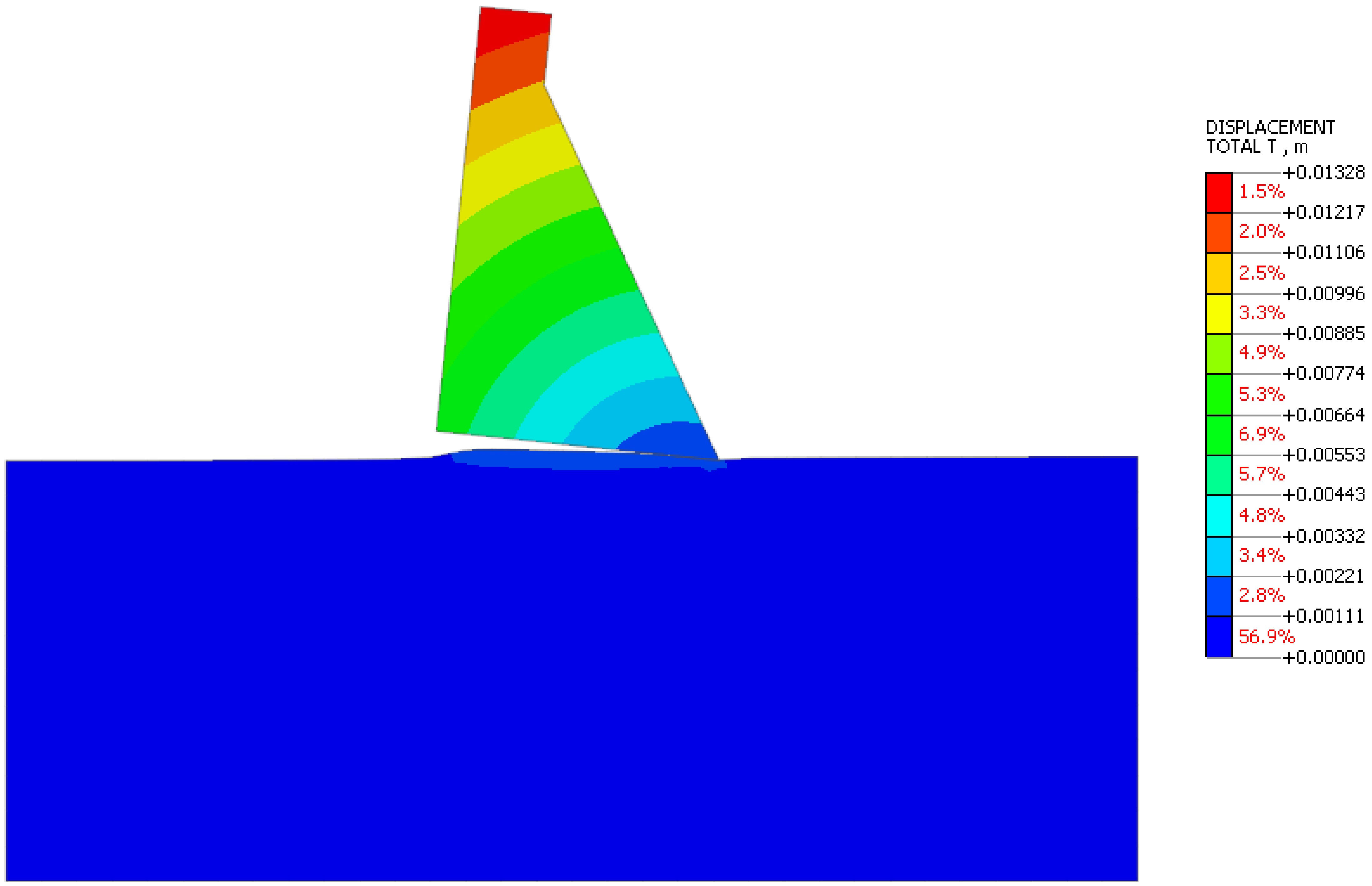
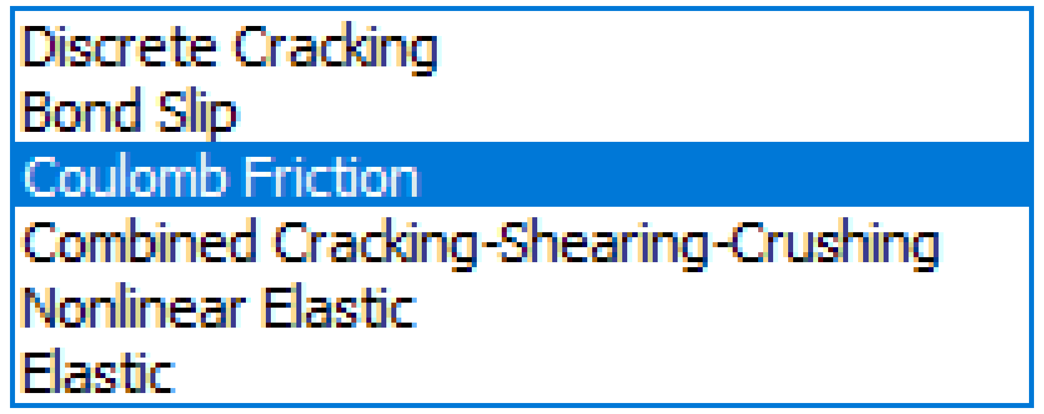
Tension Crack

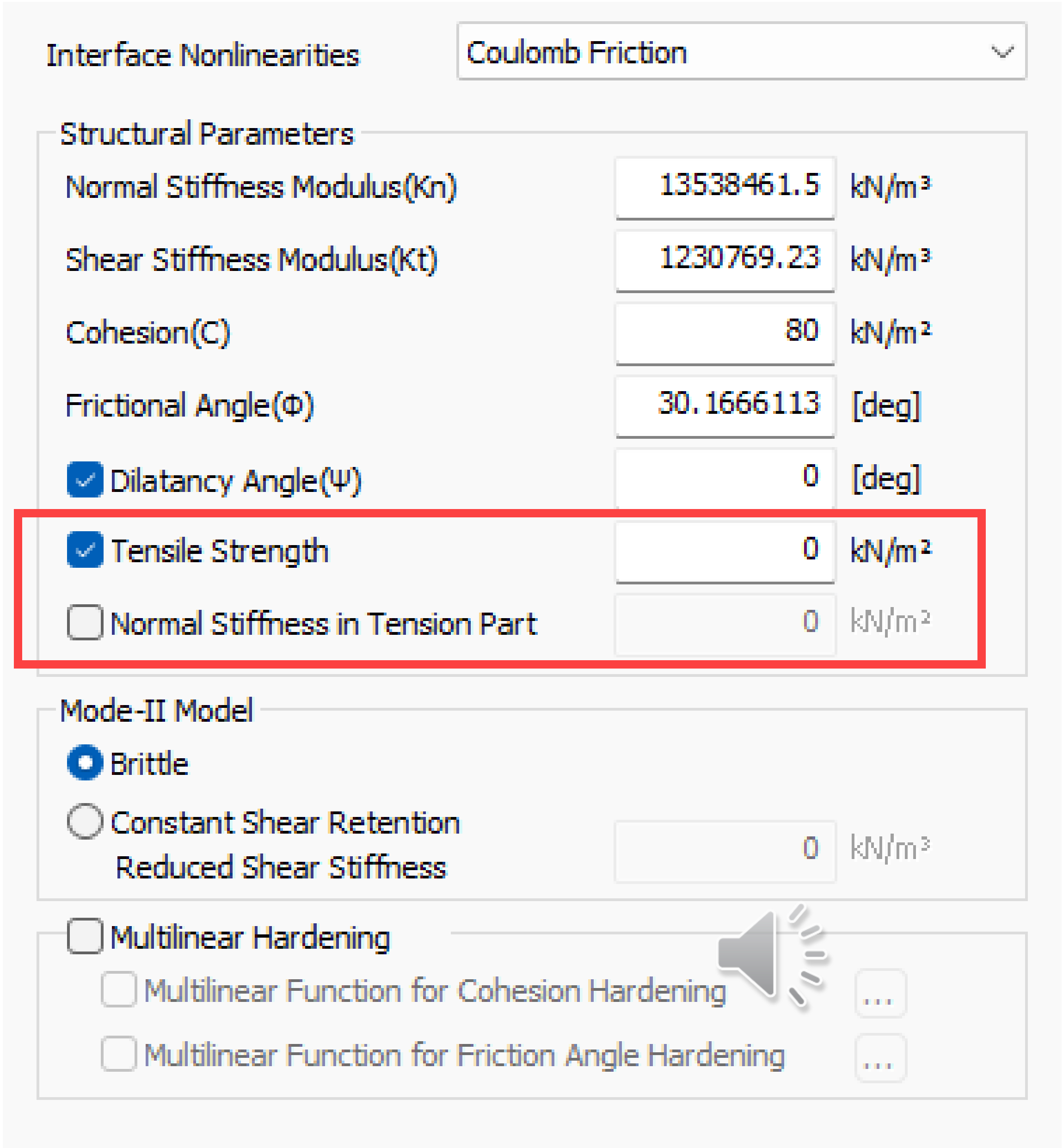
Tension Crack can be simulated using the Interface elements in FEA NX

Dam Rock Interface Types:

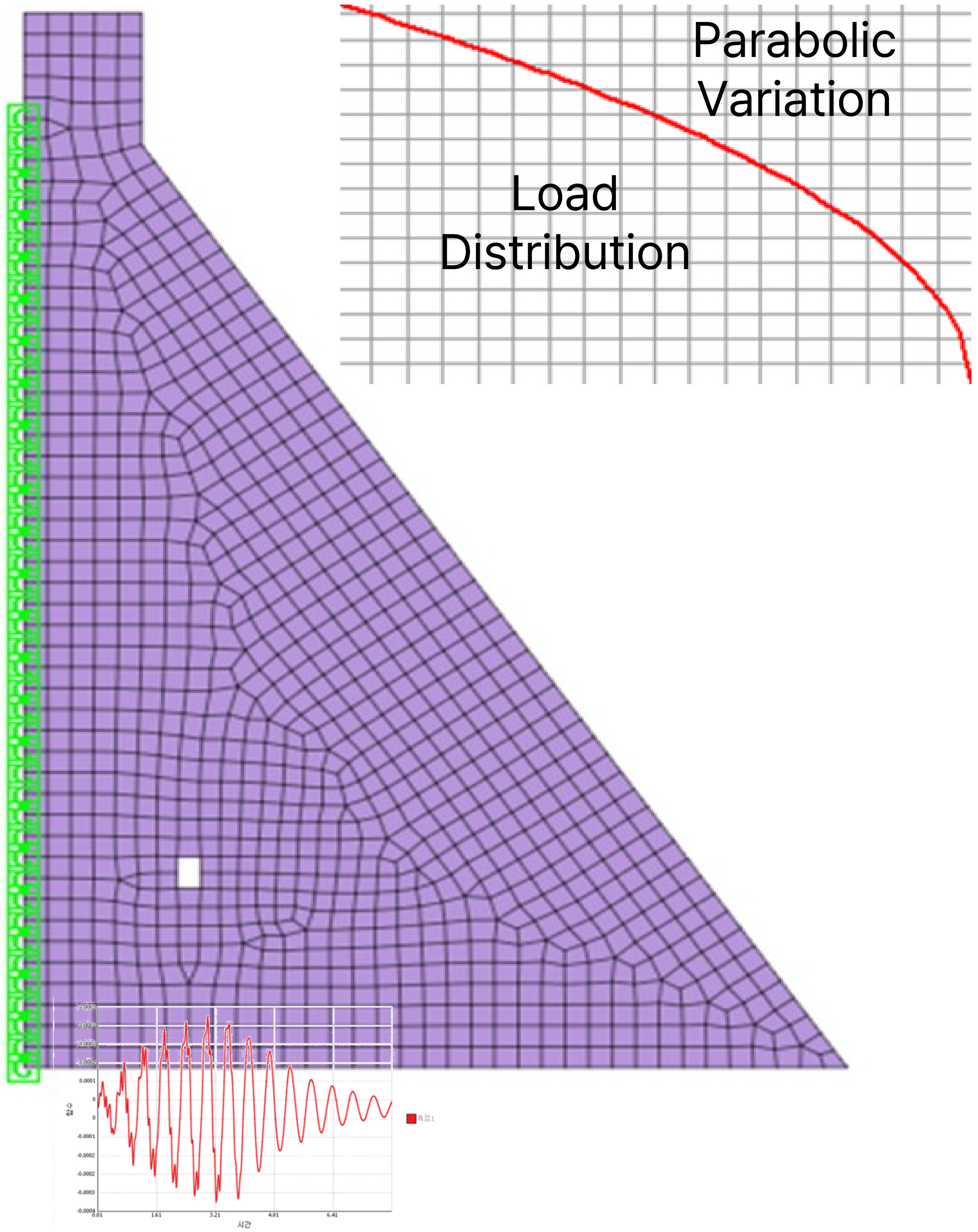
1. Linear
2. Nonlinear – Plastic, Slip, Combined Cracking, Shearing & crushing







Fluid Structure Interaction



Methods of Hydrodynamic Load Application:
1. Added Mass Method
2. Sloshing Fluid

Added Mass:
1. Westergaard's added mass method
2. C.N. Zangar's added mass method

Overview of Added Mass Concept:
- The orientation of the pressure is normal to the face of the structure.
- Load distribution is parabolic in nature.
- Suitable for other Hydraulic Structures as well.

Fluid Structure Interaction

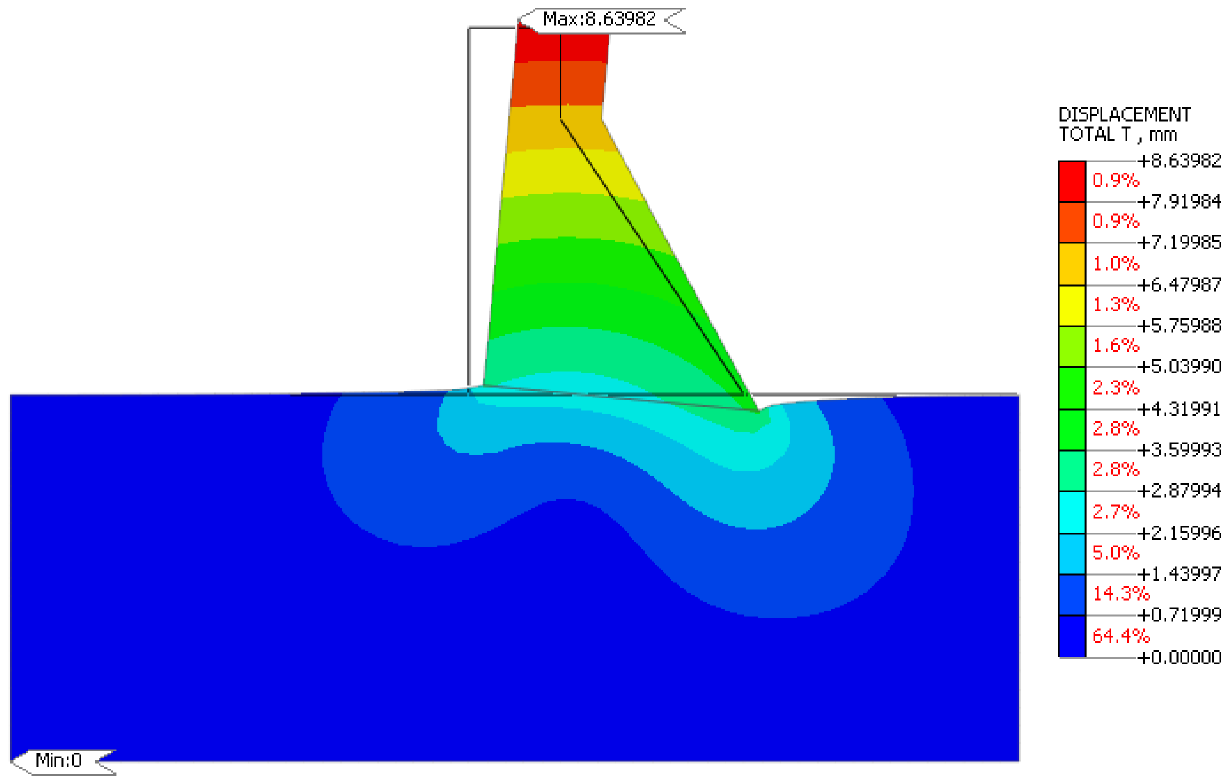
Overview of Sloshing Medium:

- Allows of wave propagation in water, sloshing effects, and the associated dynamic pressures on the dam.
- Water is not rigid, unlike the assumption in Westergaard's theory.
- Failure mode shape may differ from the Added Mass Concept.
- Do account for the movement of water relative to dam.
- Suitable when dam is flexible, and the reservoir is deep.

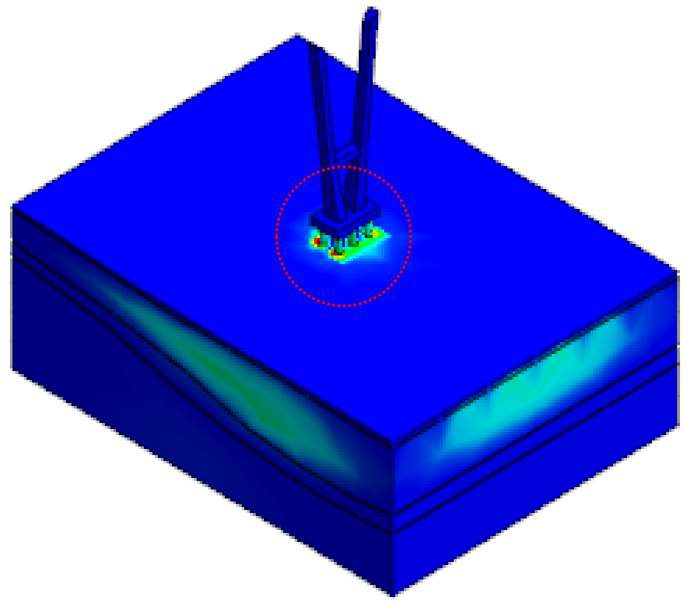
Seismic Analysis

Full Range of Seismic Analysis – All in One Solution

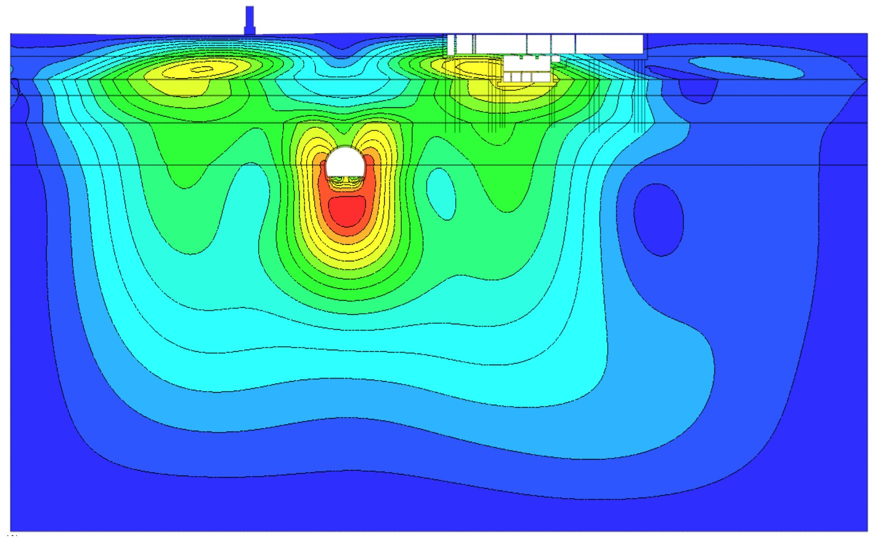
FEA NX provides all in one solution for Seismic Assessment ranging from Pseudo-Static Method, Eigenvalue, Response Spectrum Method, 1D Ground Response Analysis, Deconvolution, 2D Equivalent Linear Method, and Time History Analysis (Direct & Modal Linear/Non-Linear).



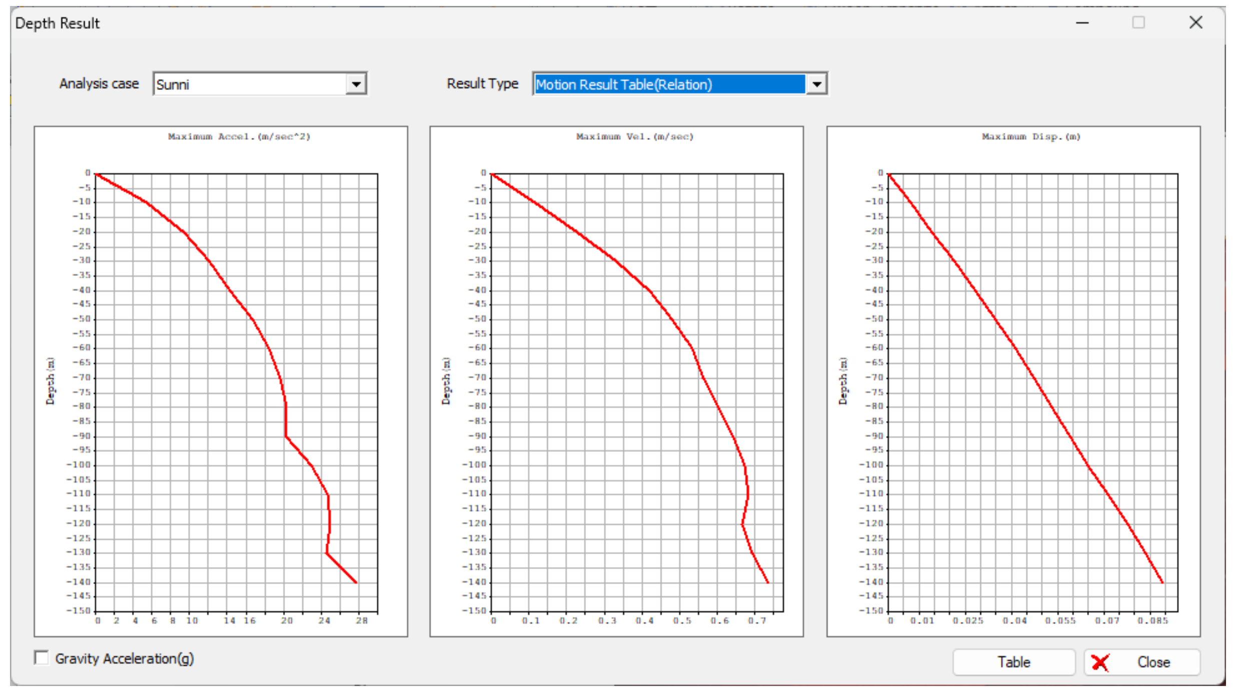
Pseudo-Static Load on the Dam Body



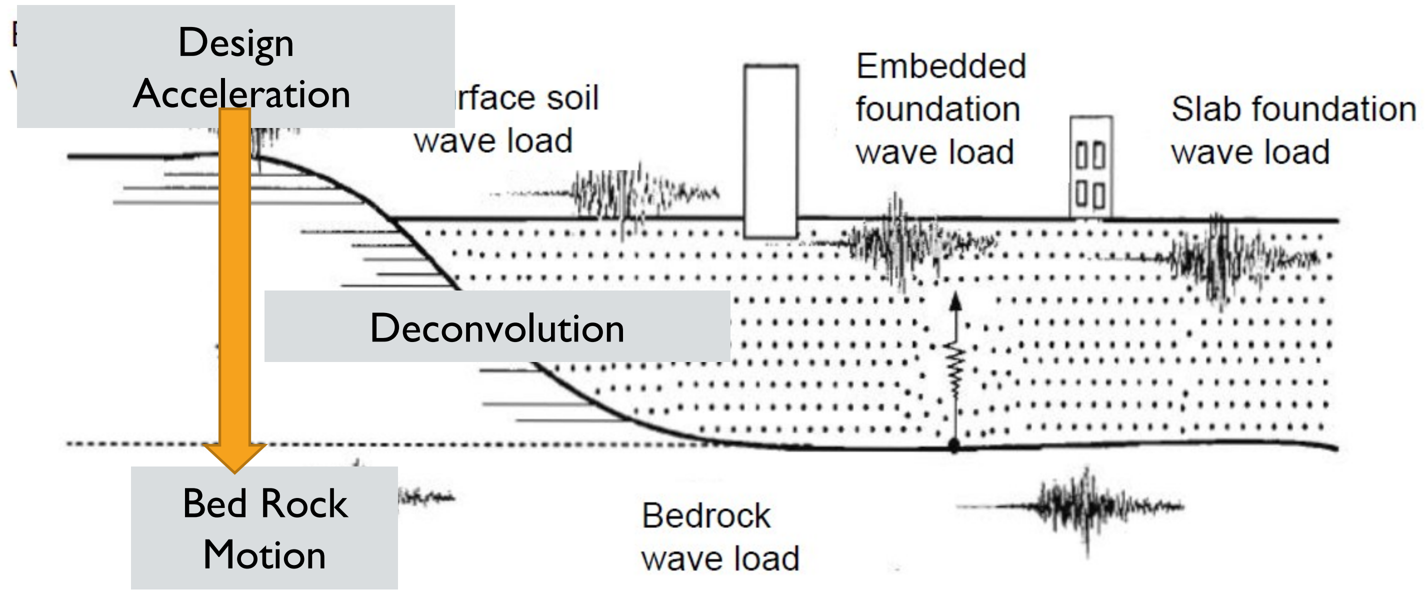
Eigenvalue



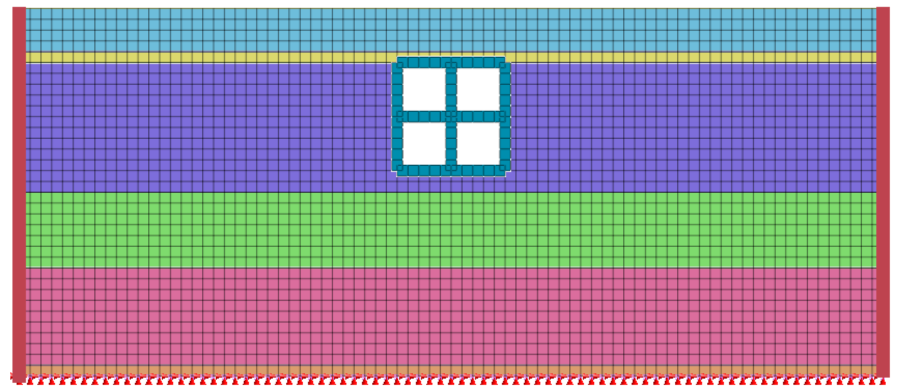
Response Spectrum



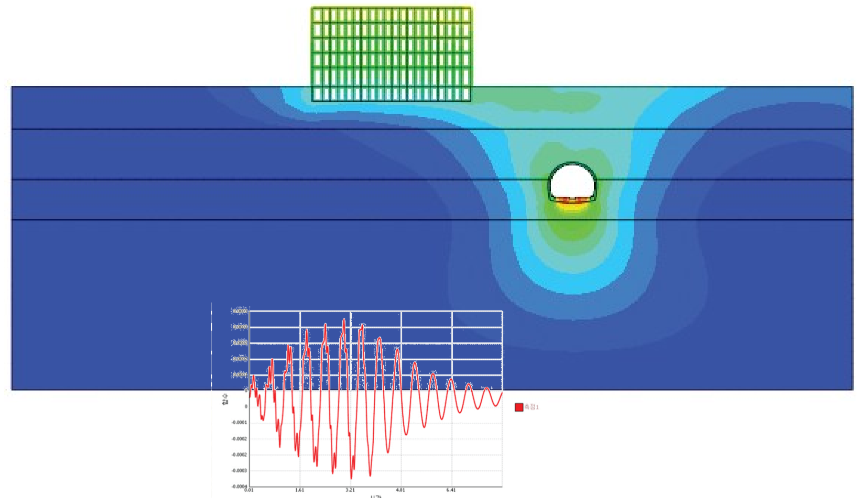
1D Ground Response Analysis



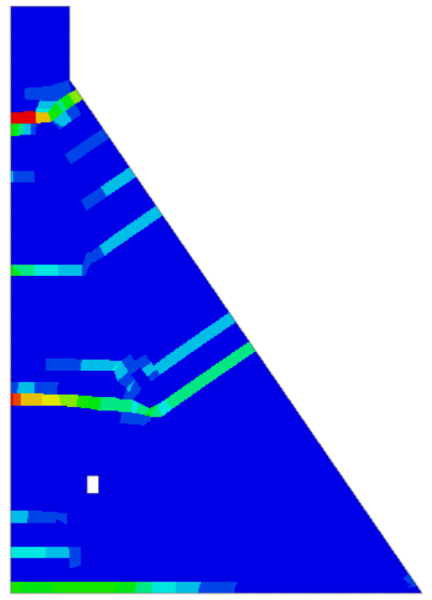
Deconvolution



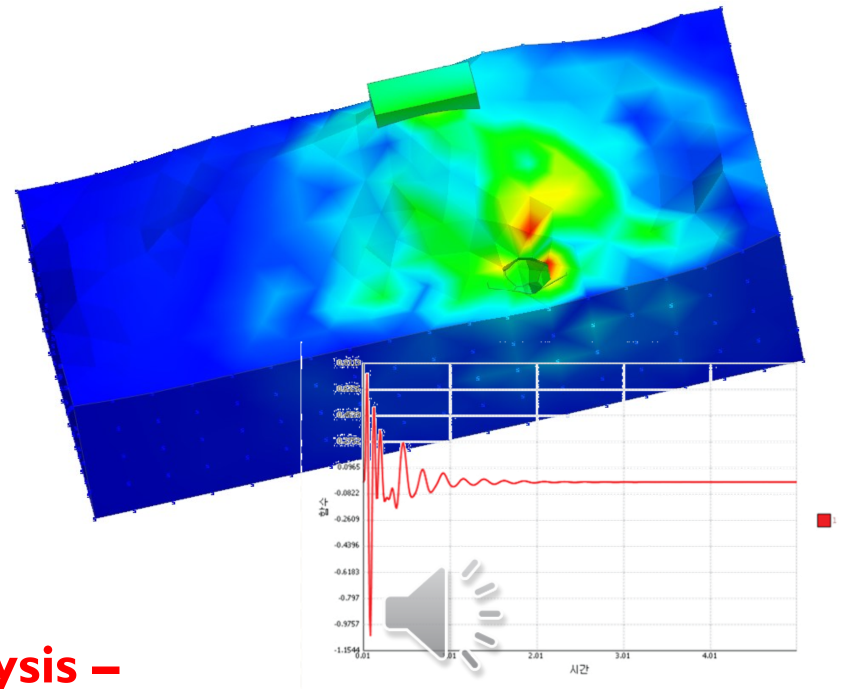
2D Equivalent Linear



Time History Analysis

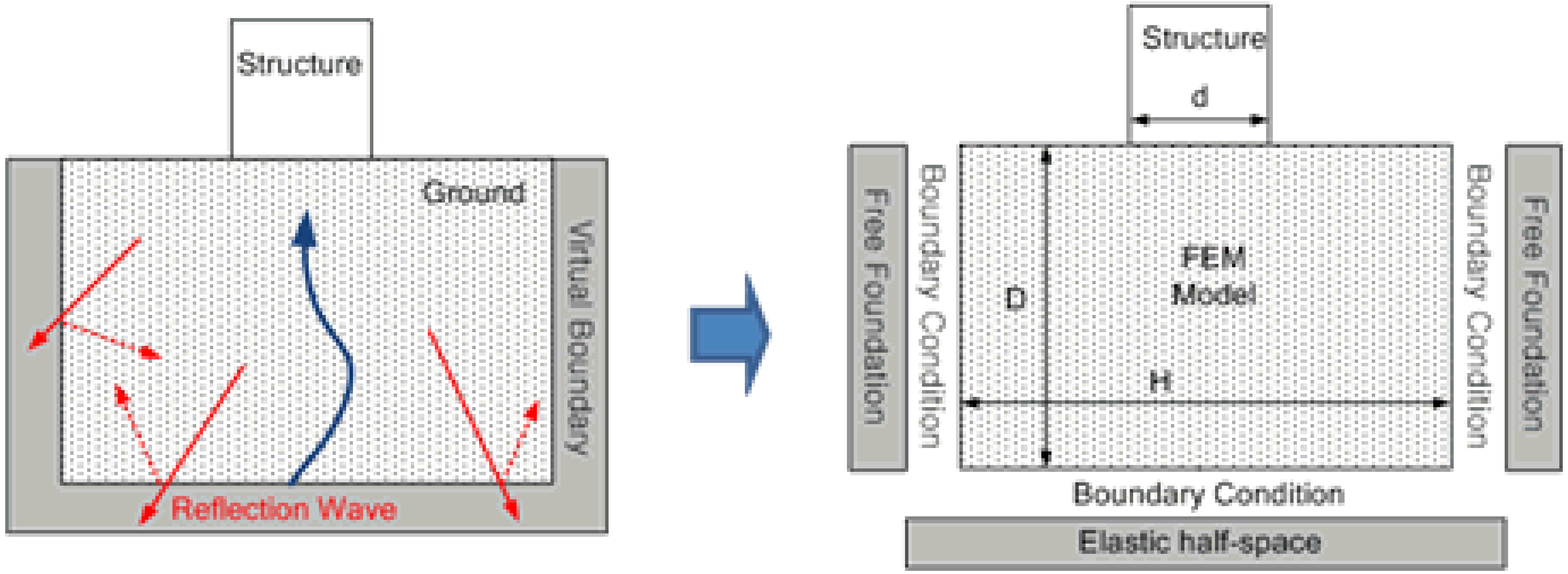


Time History Analysis – Concrete Crack



Time History Analysis – Blasting

Boundary Conditions for Seismic Analysis

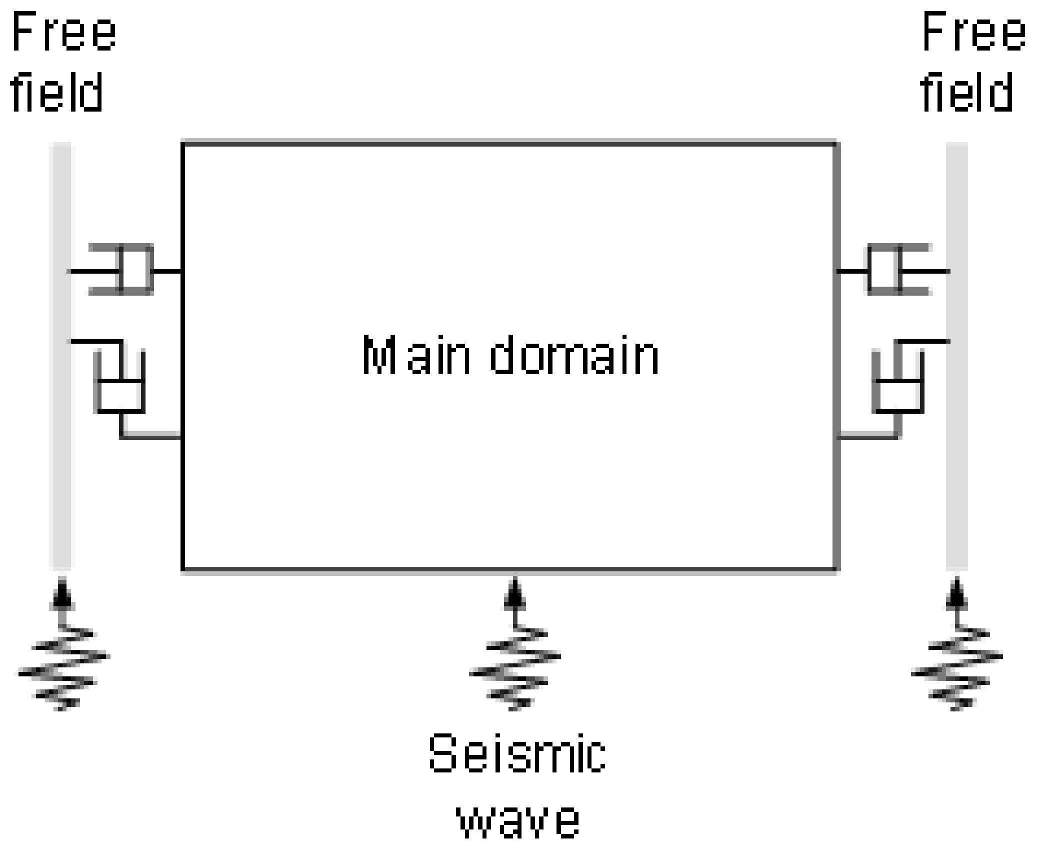


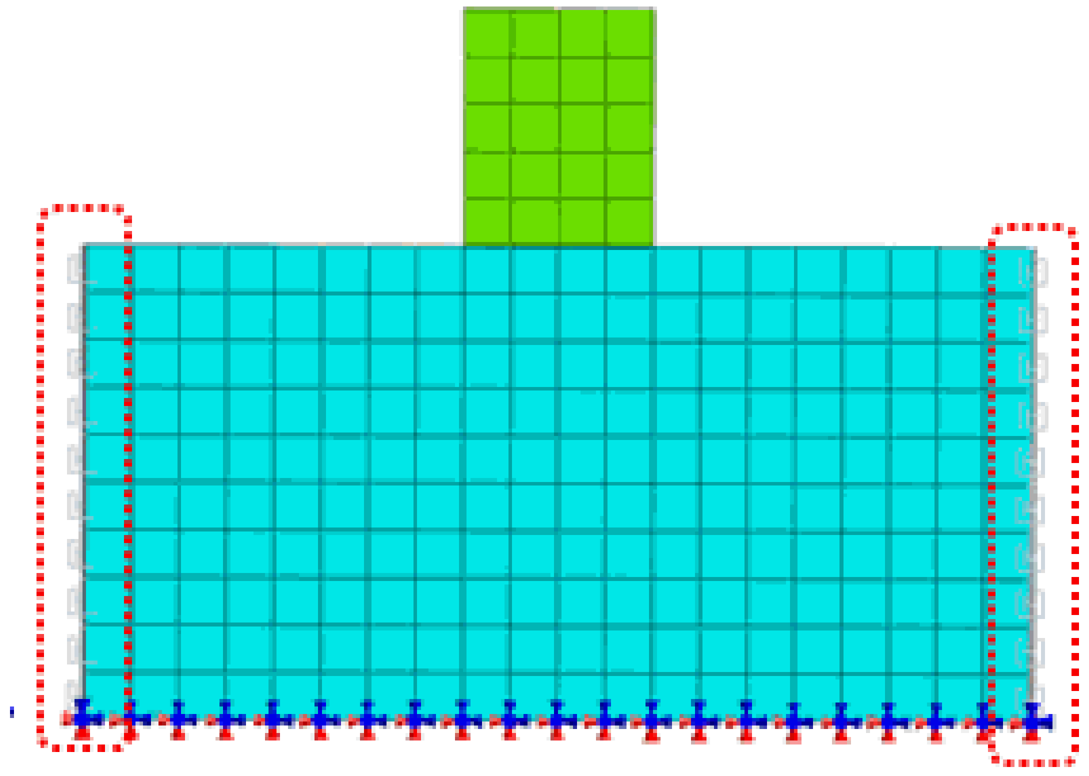
<Schematic diagram of analysis domain and FEM modeling>

Boundary Conditions

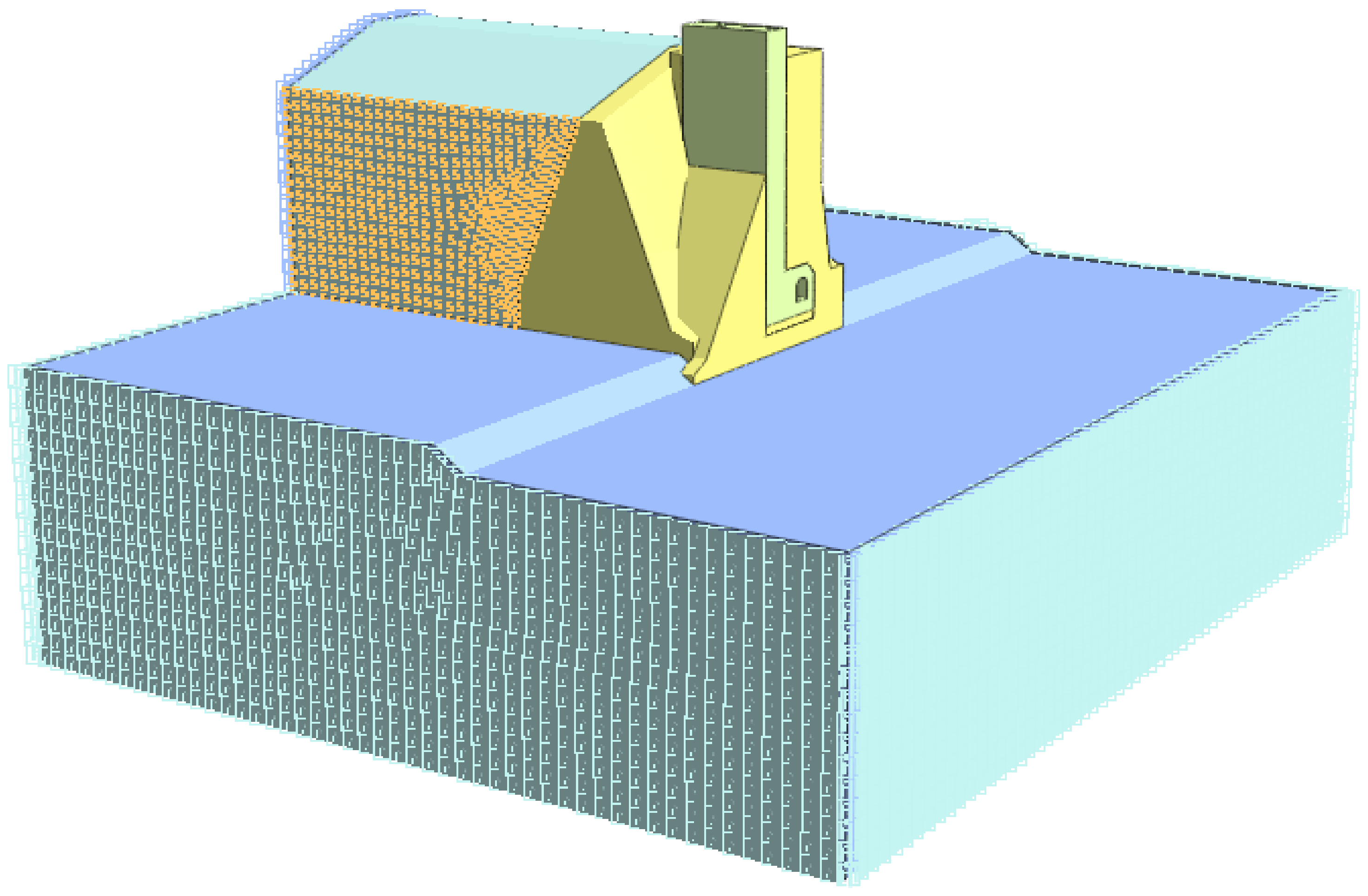
Infinite Boundaries

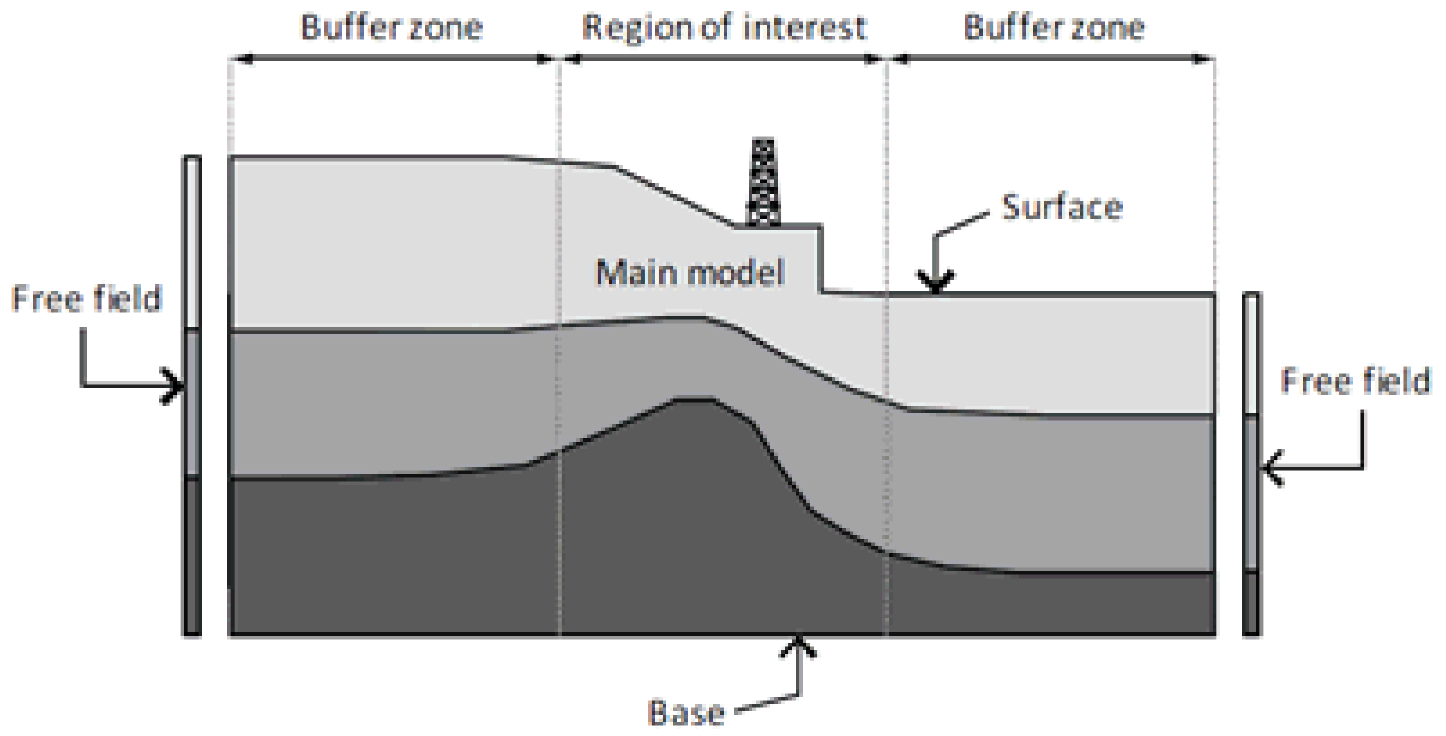
1. Free Field
2. Absorbent





[Free Field]

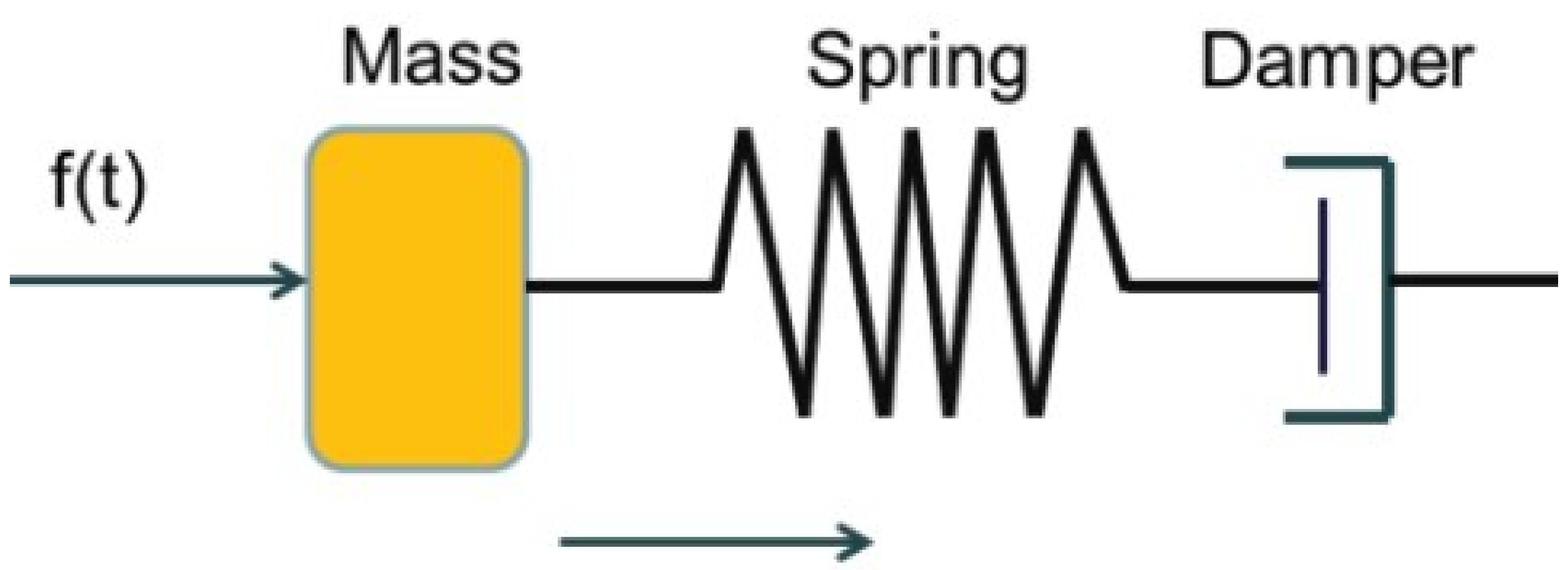


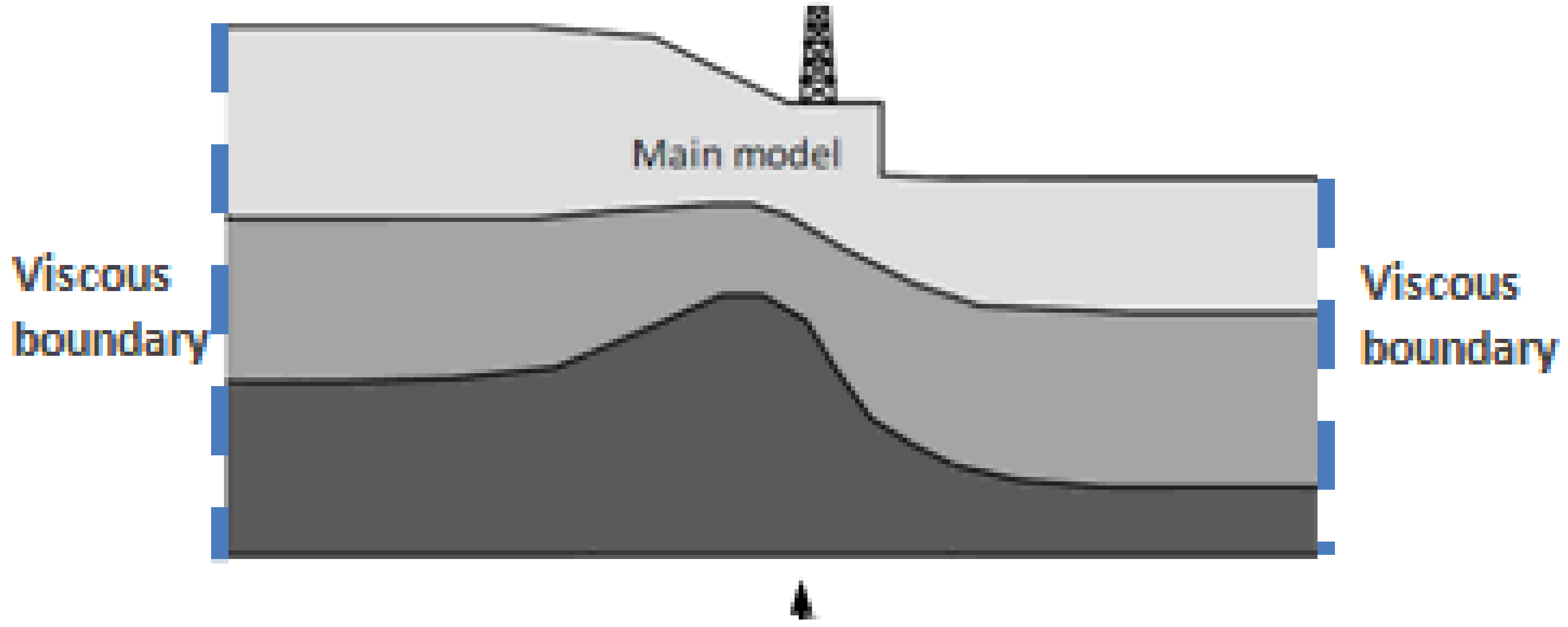


Free-Field Boundary Conditions

Boundary Conditions

Infinite Boundaries





- Modulus of subgrade reaction (Auto-calculated)

$$K_H = k_{h0}\left(\frac{B_h}{30}\right)^{-3/4} \qquad k_{h0} = \frac{1}{30}\alpha \cdot E_0$$

$$K_V = k_{v0}\left(\frac{B_v}{30}\right)^{-3/4} \qquad k_{v0} = \frac{1}{30}\alpha \cdot E_0$$

K_H : Horizontal subgrade reaction (kN/m^3)
K_V : Vertical subgrade reaction (kN/m^3)
k_{h0} : Hori. Subgrade reaction from PBT (30cm in diameter of steel plate)
k_{v0} : Ver. Subgrade reaction from PBT (30cm in diameter of steel plate)
B_h : $B_h = \sqrt{A_h}$
B_v : $B_v = \sqrt{A_v}$
A_h : Horizontal area of element face (m^2)
A_v : Vertical area of element face (m^2)
α : Modulus of elasticity coefficient (From table)

[E_0 vs α]

E_0 (kN/m^2)	α	
	Under static	Under seismic
Elastic modulus from PBT	1	2
Measured elastic modulus from boring hole	4	8
Elastic modulus from 1D or 3D compresseion test	4	8
Elastic modulus from SPT using following relation (Eo= 28*N (tonf/m²))	1	2

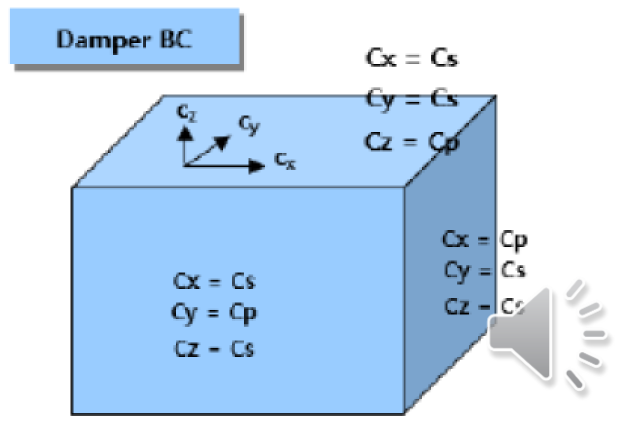
- Damping constant

Primary wave $\quad C_p = \rho \cdot A \cdot \sqrt{\frac{\lambda + 2G}{\rho}} = W \cdot A \cdot \sqrt{\frac{\lambda + 2G}{W \cdot 9.81}} = c_p \cdot A$

Secondary wave $\quad C_s = \rho \cdot A \cdot \sqrt{\frac{G}{\rho}} = W \cdot A \cdot \sqrt{\frac{G}{W \cdot 9.81}} = c_s \cdot A$

where, $\quad \lambda = \frac{\nu \cdot E}{(1+\nu)(1-2\nu)} \qquad G = \frac{E}{2(1+\nu)}$

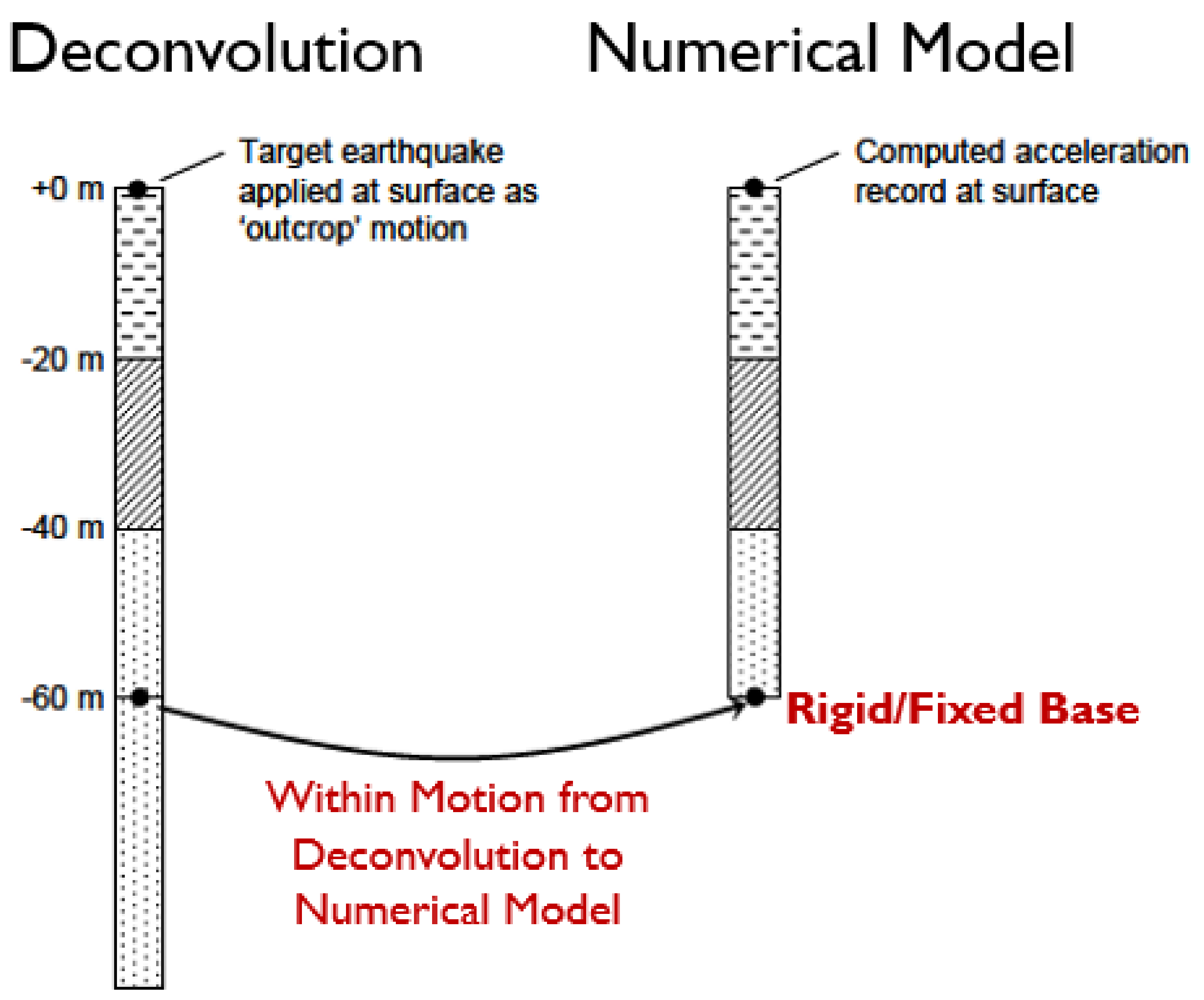
λ : Volumetric modulus (tonf/m²)
G : Shear modulus (tonf/m²)
E : Elasticity (tonf/m²)
ν : Poisson's ratio
A : Element face area (m²)

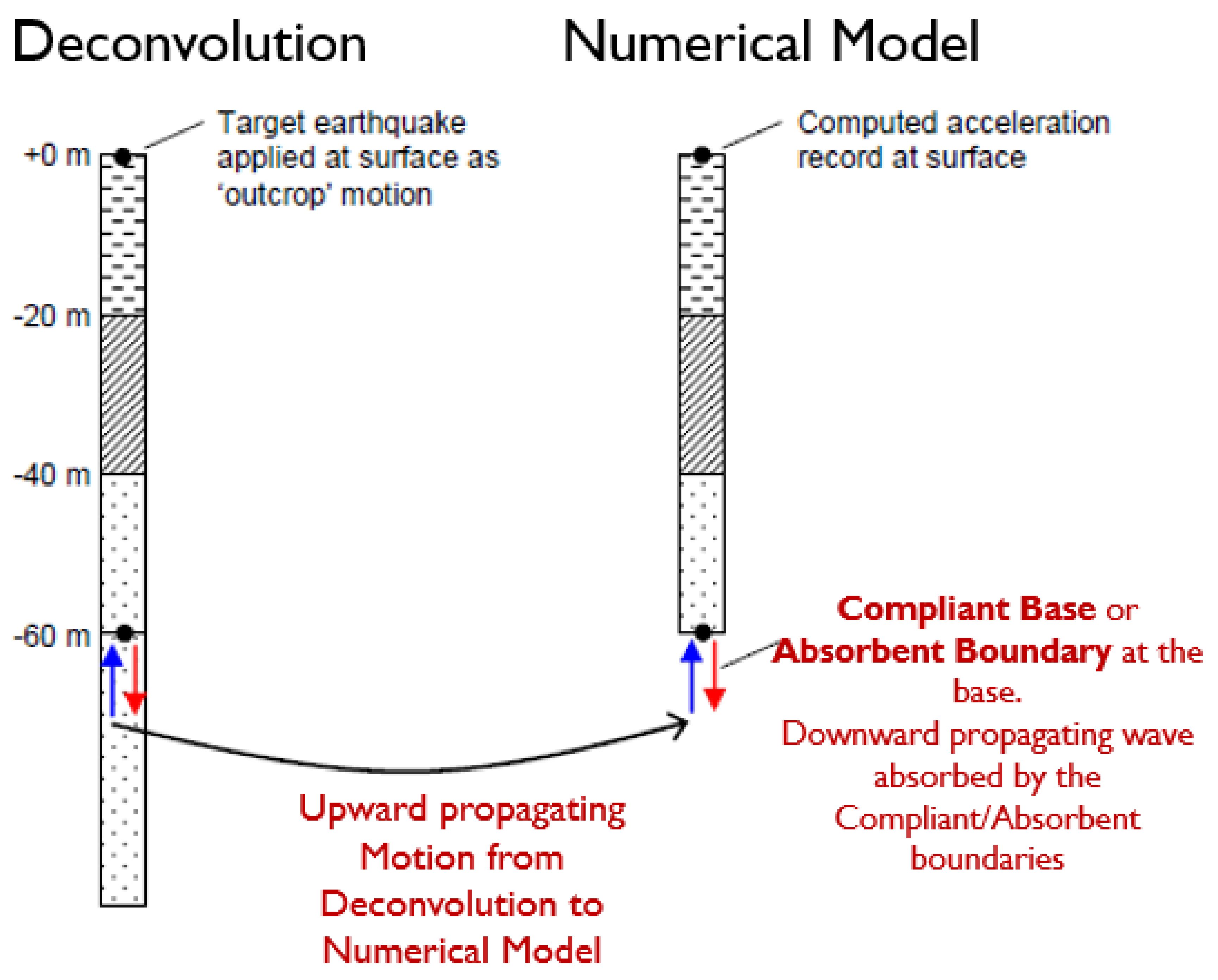


Viscous – Absorbent Boundary Conditions

Boundary Conditions

Base Boundary





Reference: Mejia, L.H. and Dawson, E.M., 2006, May. Earthquake deconvolution for FLAC. In 4th International FLAC symposium on numerical modeling in geomechanics (pp. 4-10). Citeseer.

One Stop Solution for All DAM & Hydropower related Challenges

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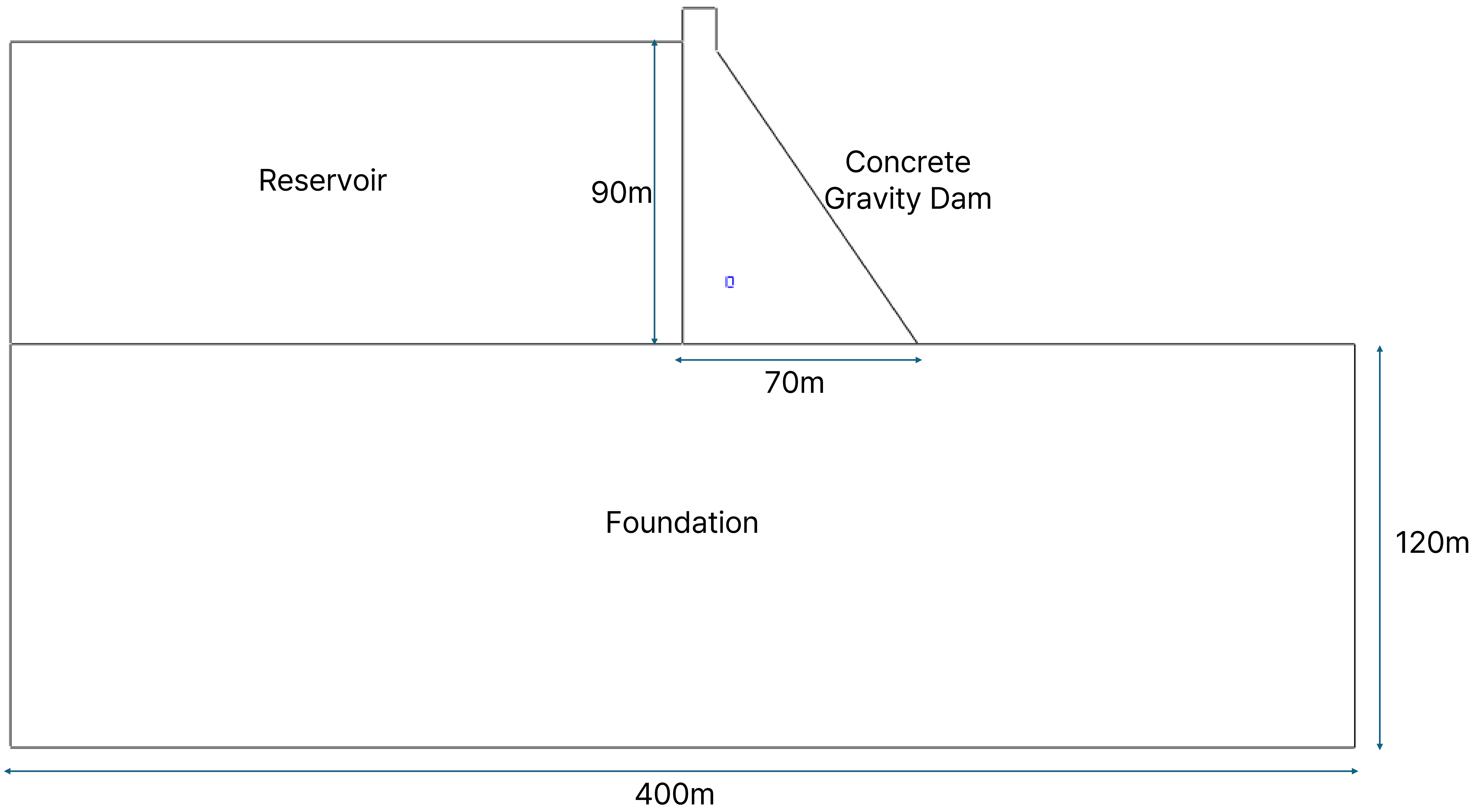
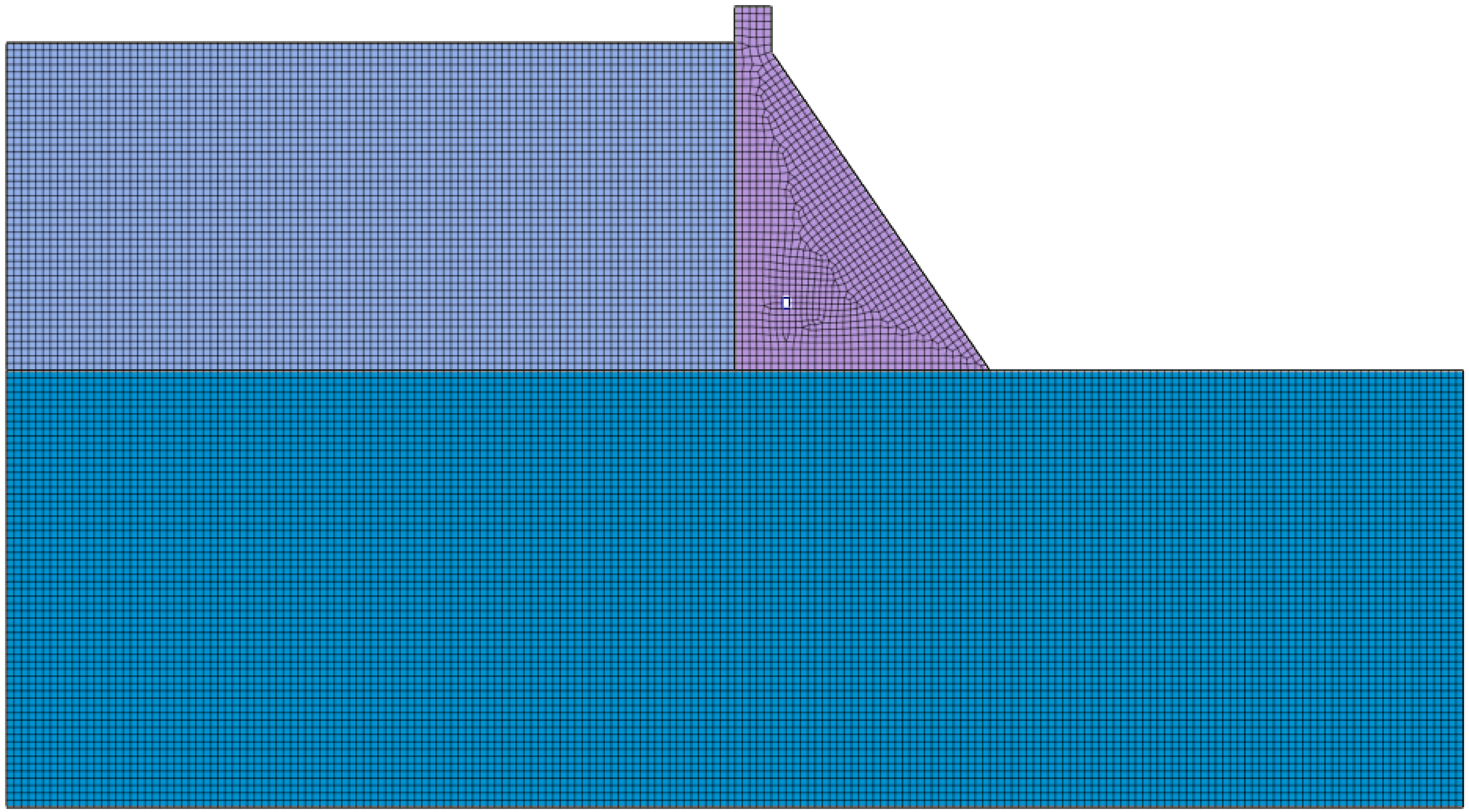
Geometry Model

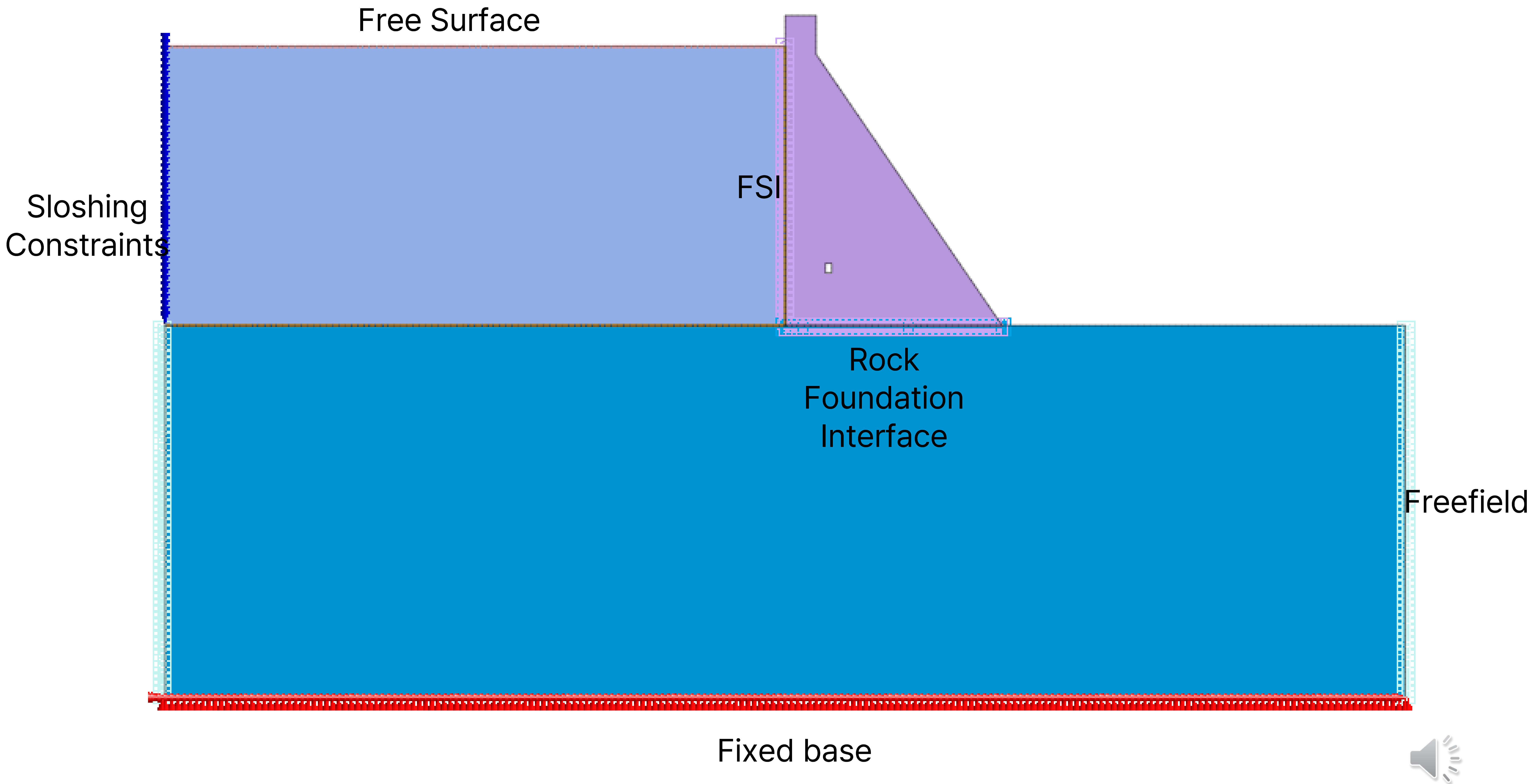


Meshing

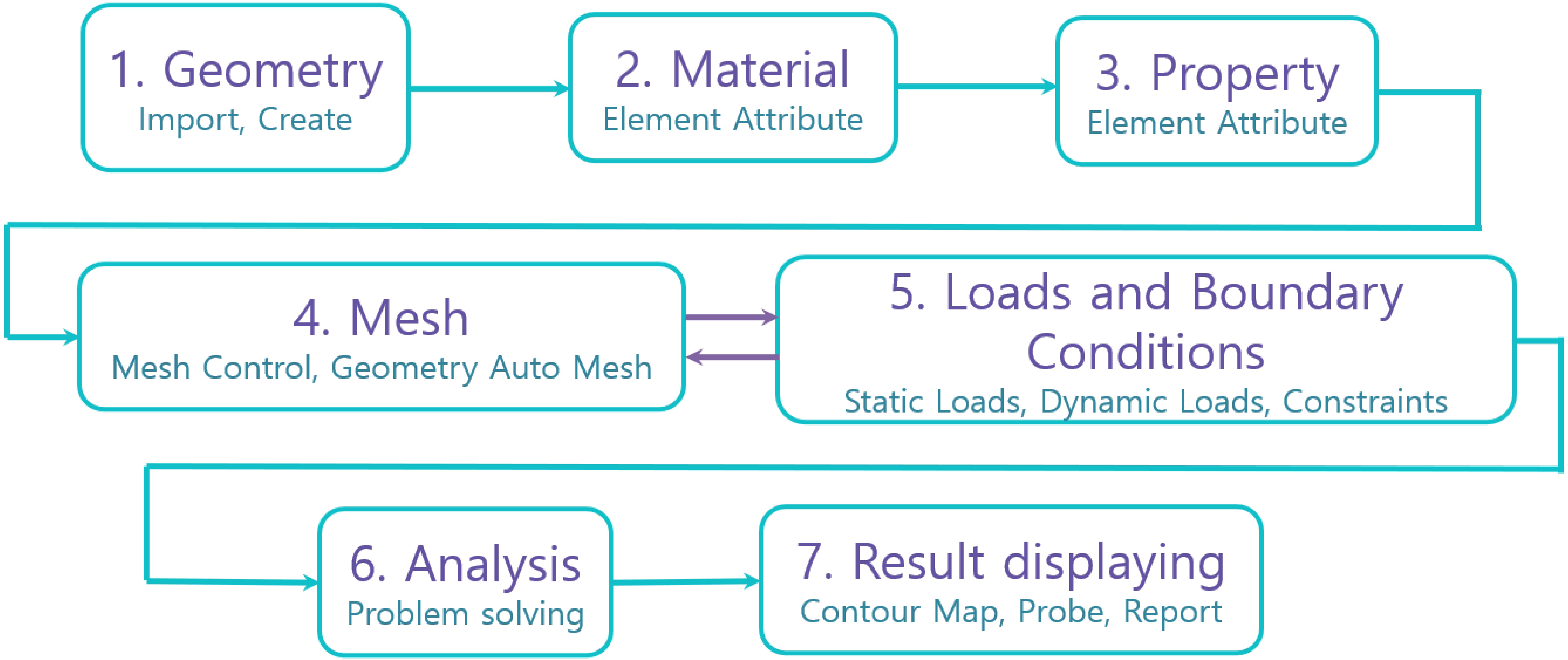


Mesh Size=2m

Boundary Conditions & FSI Definitions



General Workflow



Let’s Model!!

Thanks for Attending!!

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