

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

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01 Challenges in Concrete Gravity Dams

- Tension Crack
- Fluid Structure Interaction
- Seismic Analysis

02 FEA NX Solutions

- Foundation & Dam Interface
- Fluid Structure Interaction

03 Demonstration

- Geometry Modeling
- Definitions for Seismic Analysis

04 Result Interpretation

- Reservoir Pressure
- Amplification



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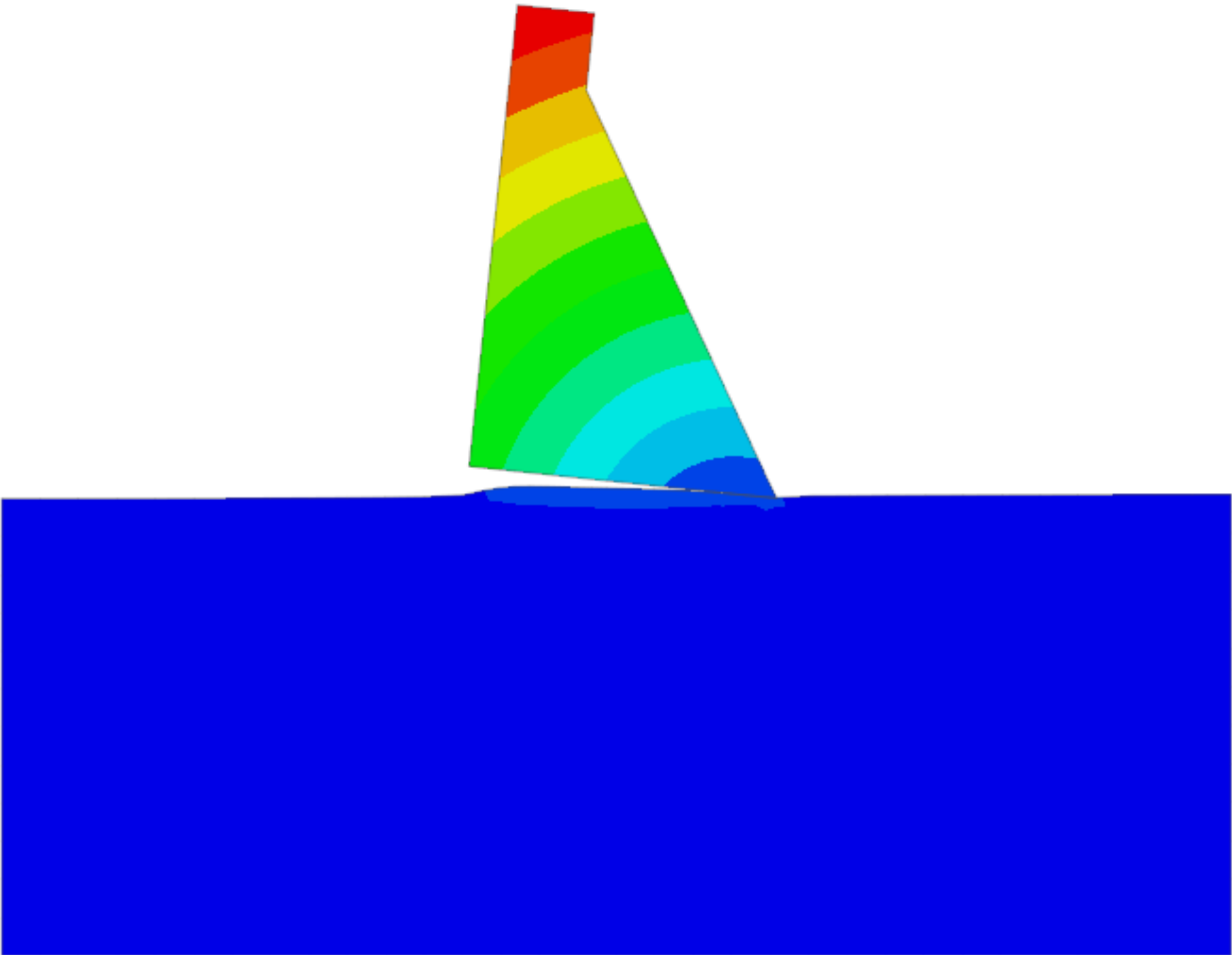
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Tension Crack



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

Discrete Cracking

Bond Slip

Coulomb Friction

Combined Cracking-Shearing-Crushing

Nonlinear Elastic

Elastic

Interface Nonlinearities

Coulomb Friction

Structural Parameters

Normal Stiffness Modulus(Kn)

13538461.5

kN/m³

Shear Stiffness Modulus(Kt)

1230769.23

kN/m³

Cohesion(C)

80

kN/m²

Frictional Angle(Φ)

30.1666113

[deg]

☒ Dilatancy Angle(Ψ)

0

[deg]

☒ Tensile Strength

0

kN/m²

☐ Normal Stiffness in Tension Part

0

kN/m²

Mode-II Model

☒ Brittle

☐ Constant Shear Retention

0

kN/m³

☐ Reduced Shear Stiffness

☐ Multilinear Hardening

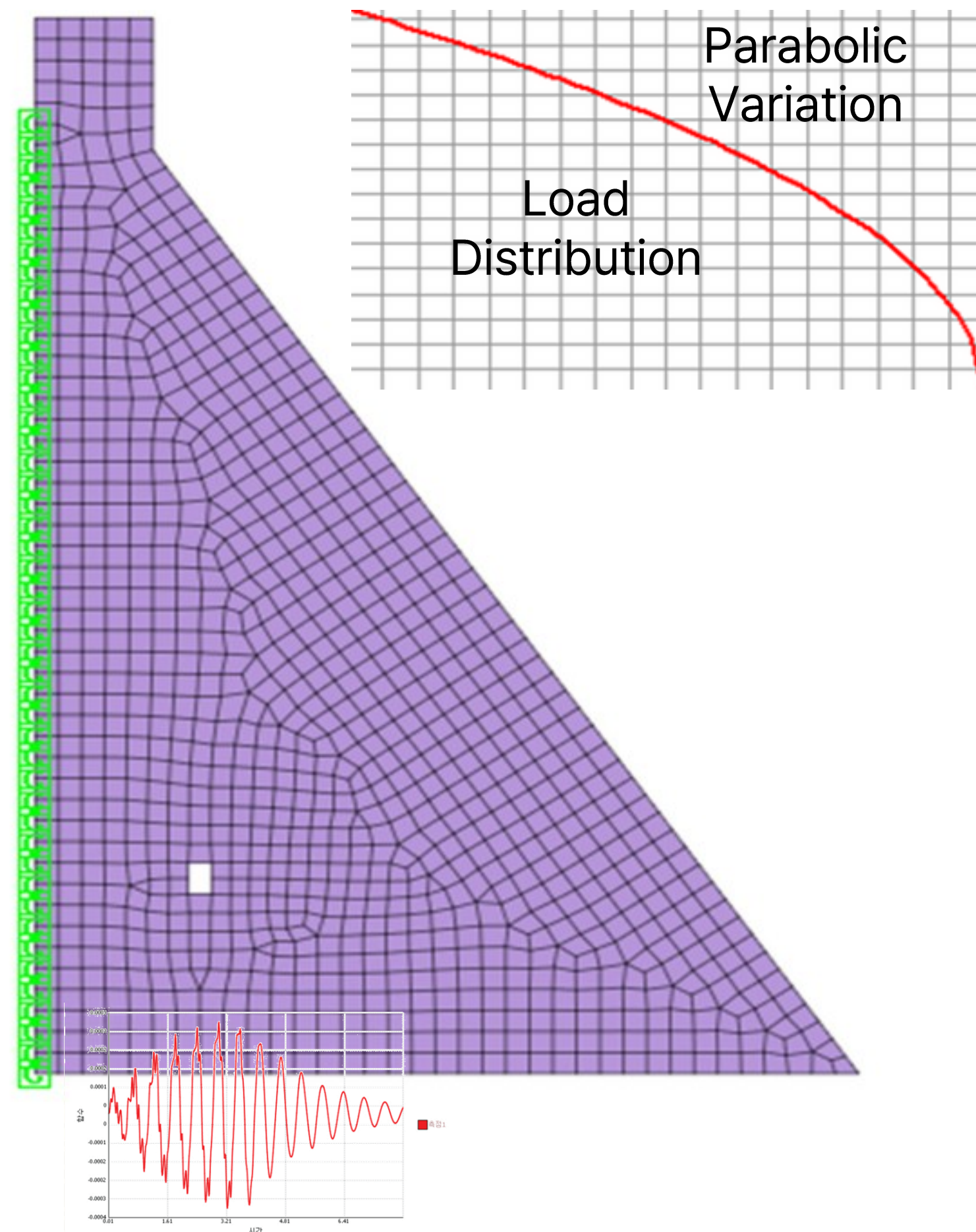
☐ Multilinear Function for Cohesion Hardening

...

☐ Multilinear Function for Friction Angle Hardening

...

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:

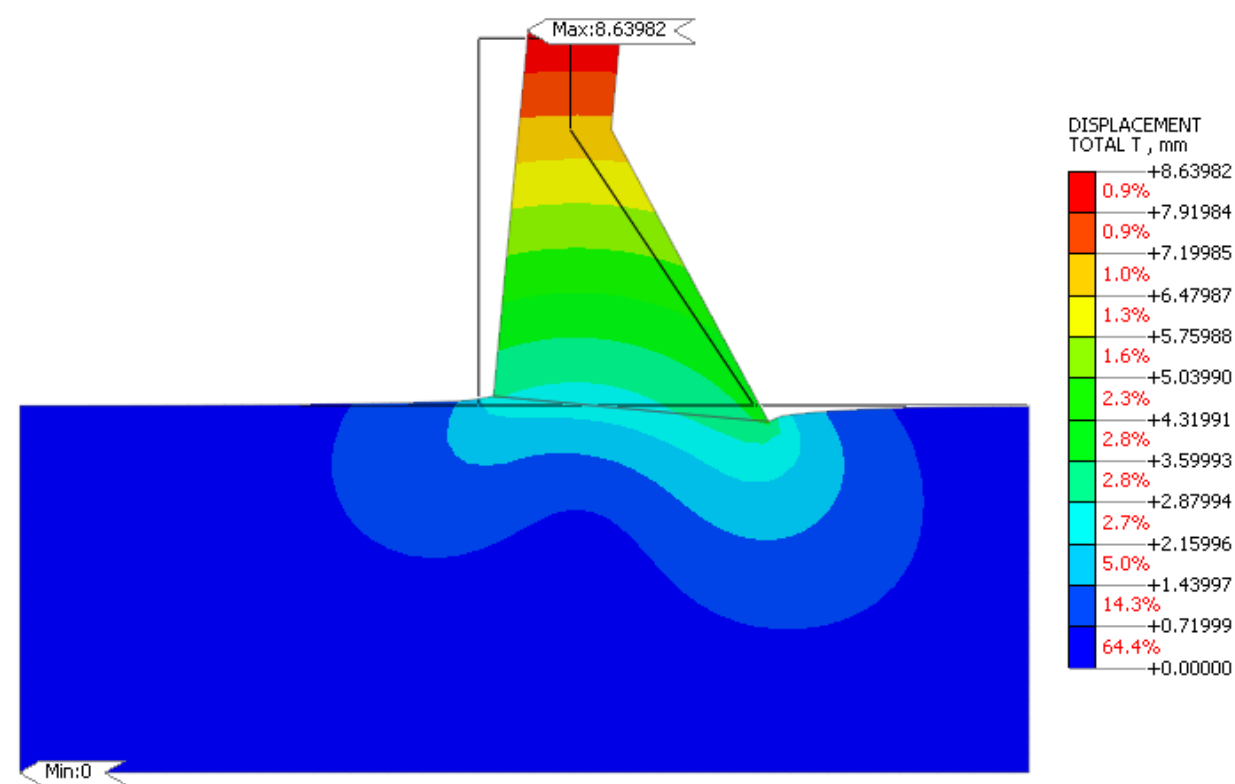
- Allows of wave propagation in water, sloshing effects, and the associated dynamic pressures on the dam.
- Water is not rigid, unlike the assumption in Westergaard's theory.
- Failure mode shape may differ from the Added Mass Concept.
- Do account for the movement of water relative to dam.
- Suitable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



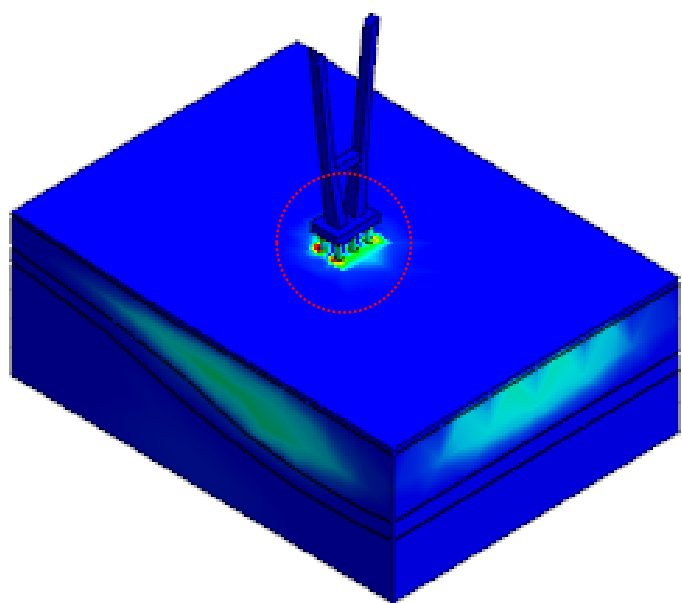
Seismic Analysis

Full Range of Seismic Analysis – All in One Solution

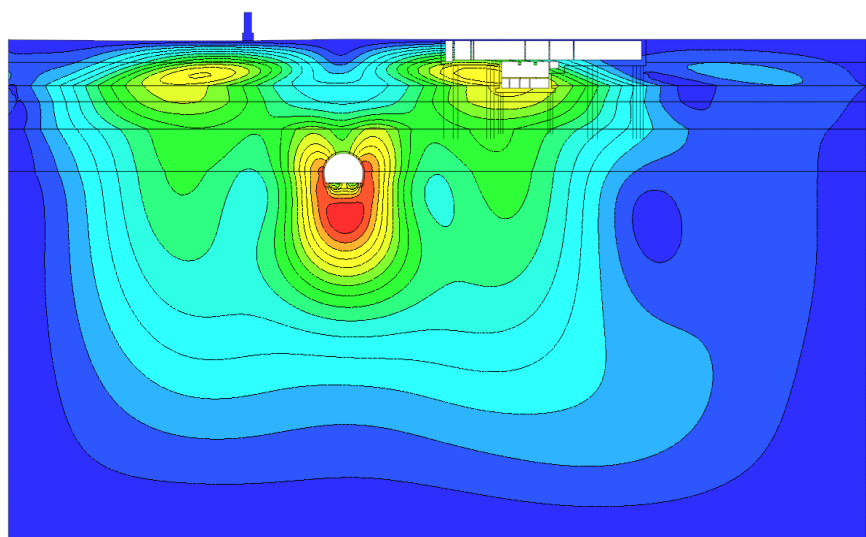
FEA NX provides all in one solution for Seismic Assessment ranging from Pseudo-Static Method, Eigenvalue, Response Spectrum Method, ID Ground Response Analysis, Deconvolution, 2D Equivalent Linear Method, and Time History Analysis (Direct & Modal Linear/Non-Linear).



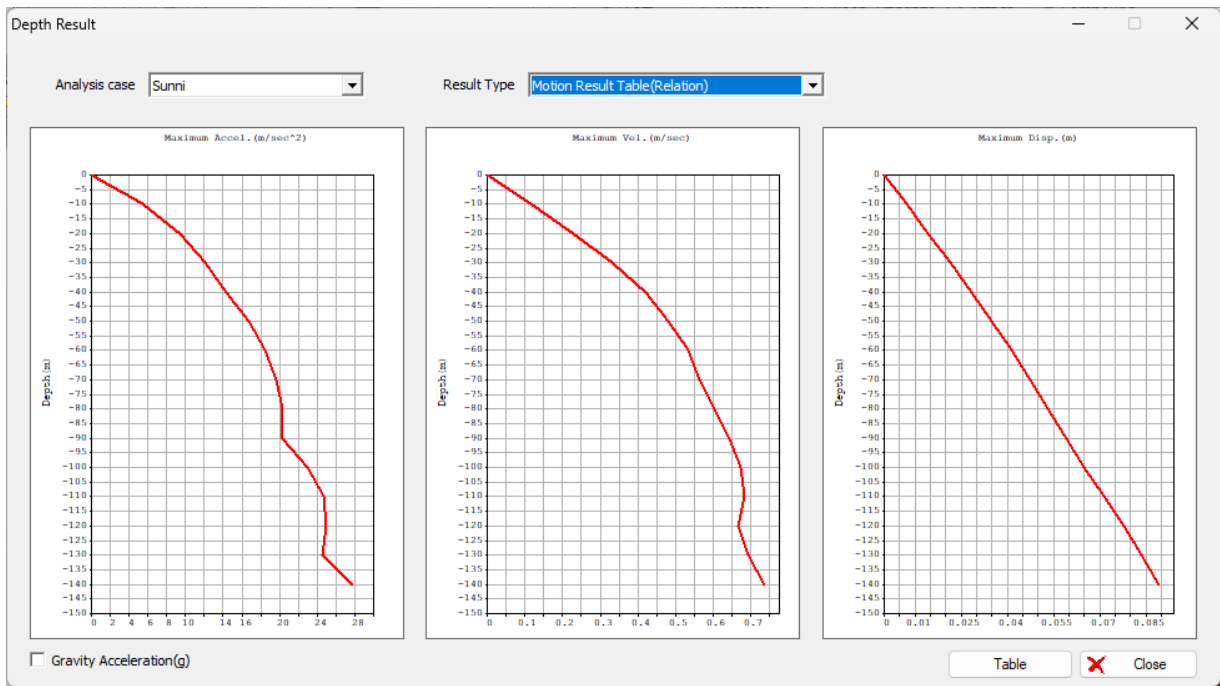
Pseudo-Static Load on the Dam Body



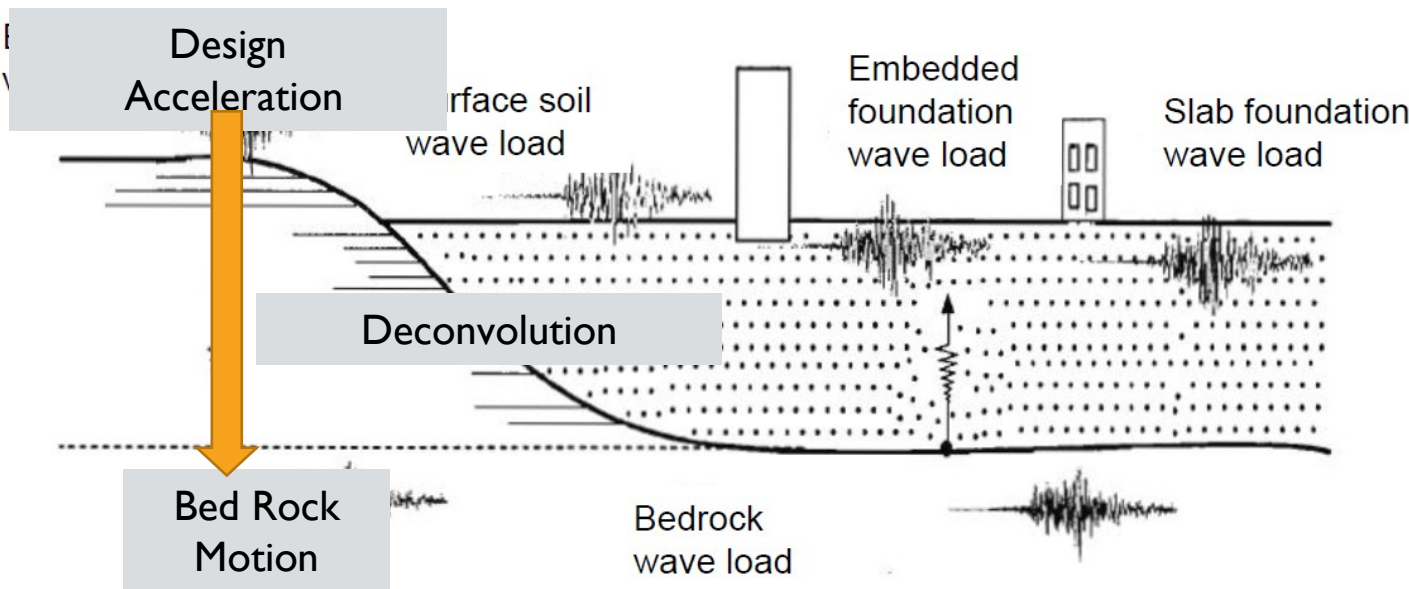
Eigenvalue



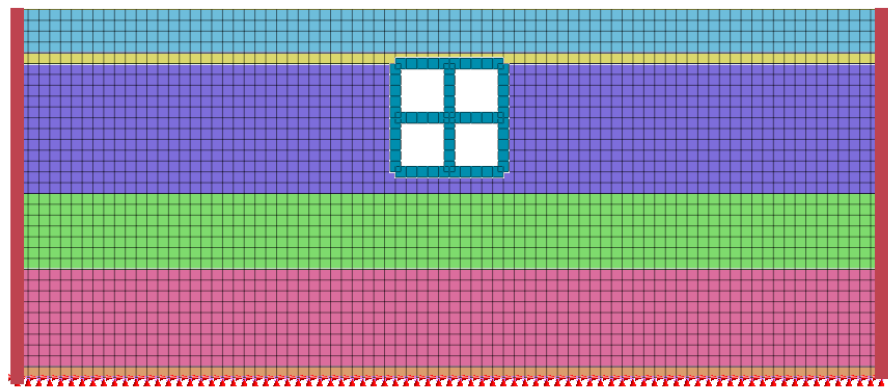
Response Spectrum



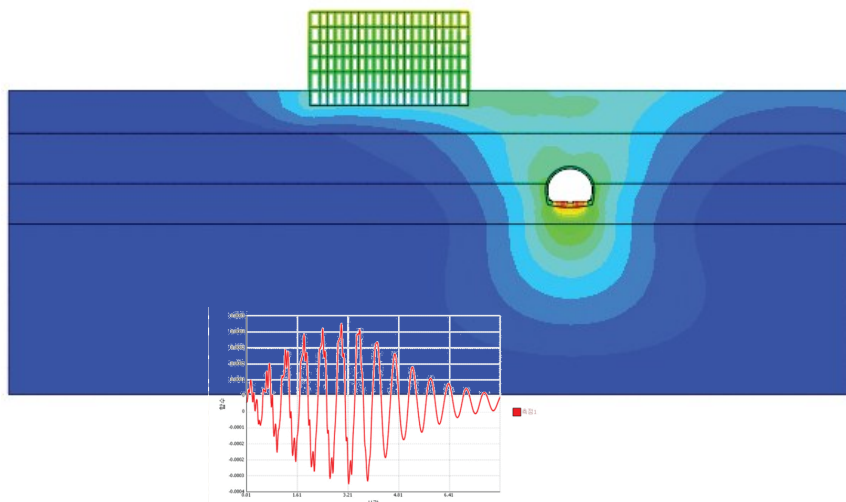
ID Ground Response Analysis



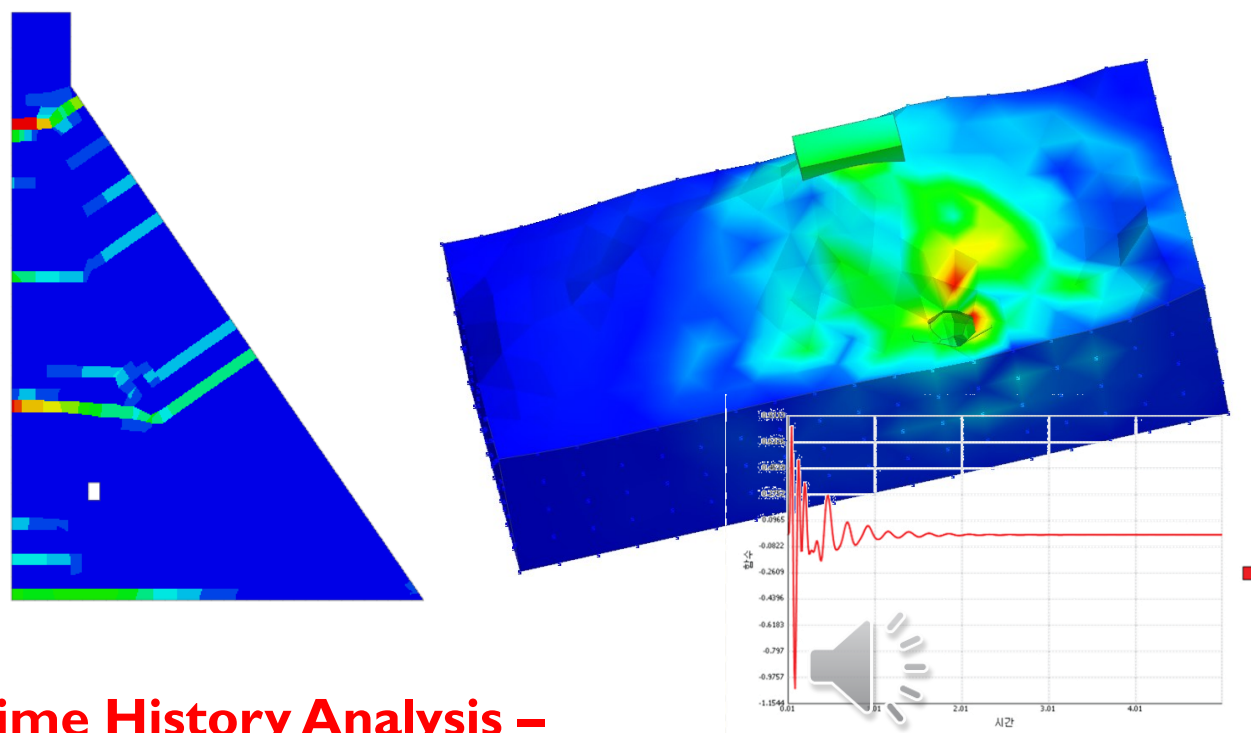
Deconvolution



2D Equivalent Linear



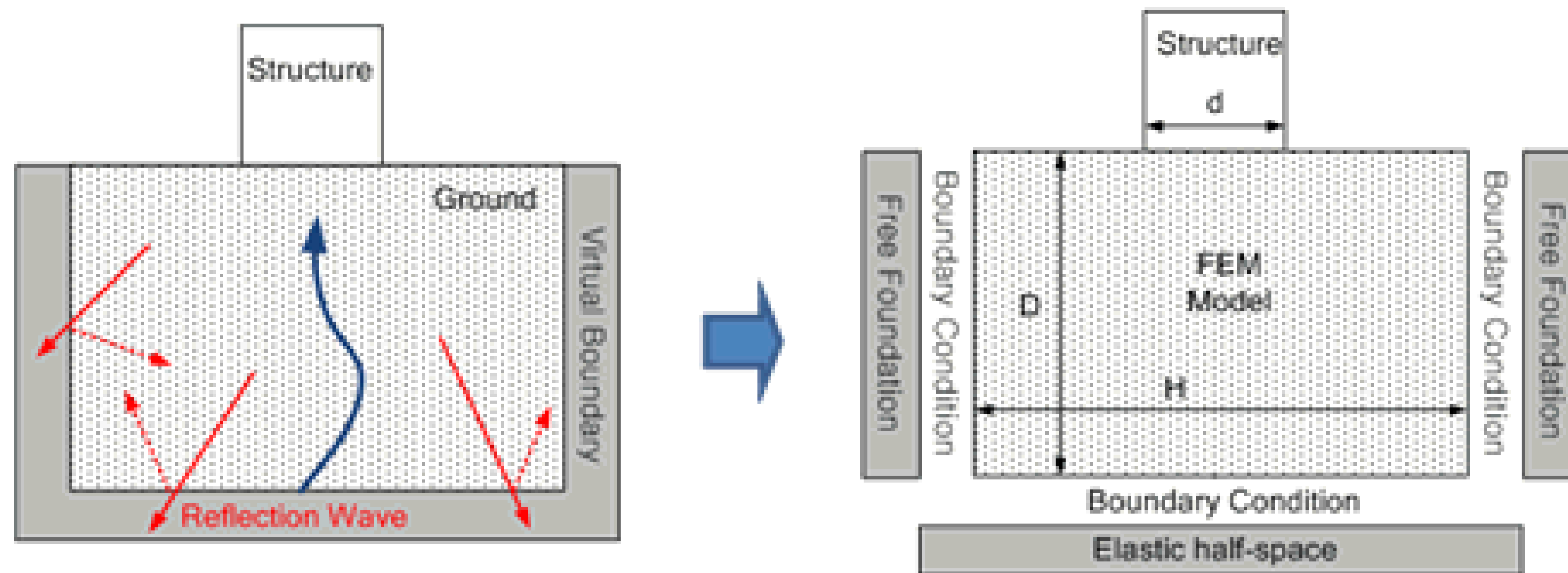
Time History Analysis



Time History Analysis – Concrete Crack

Time History Analysis – Blasting

Boundary Conditions for Seismic Analysis



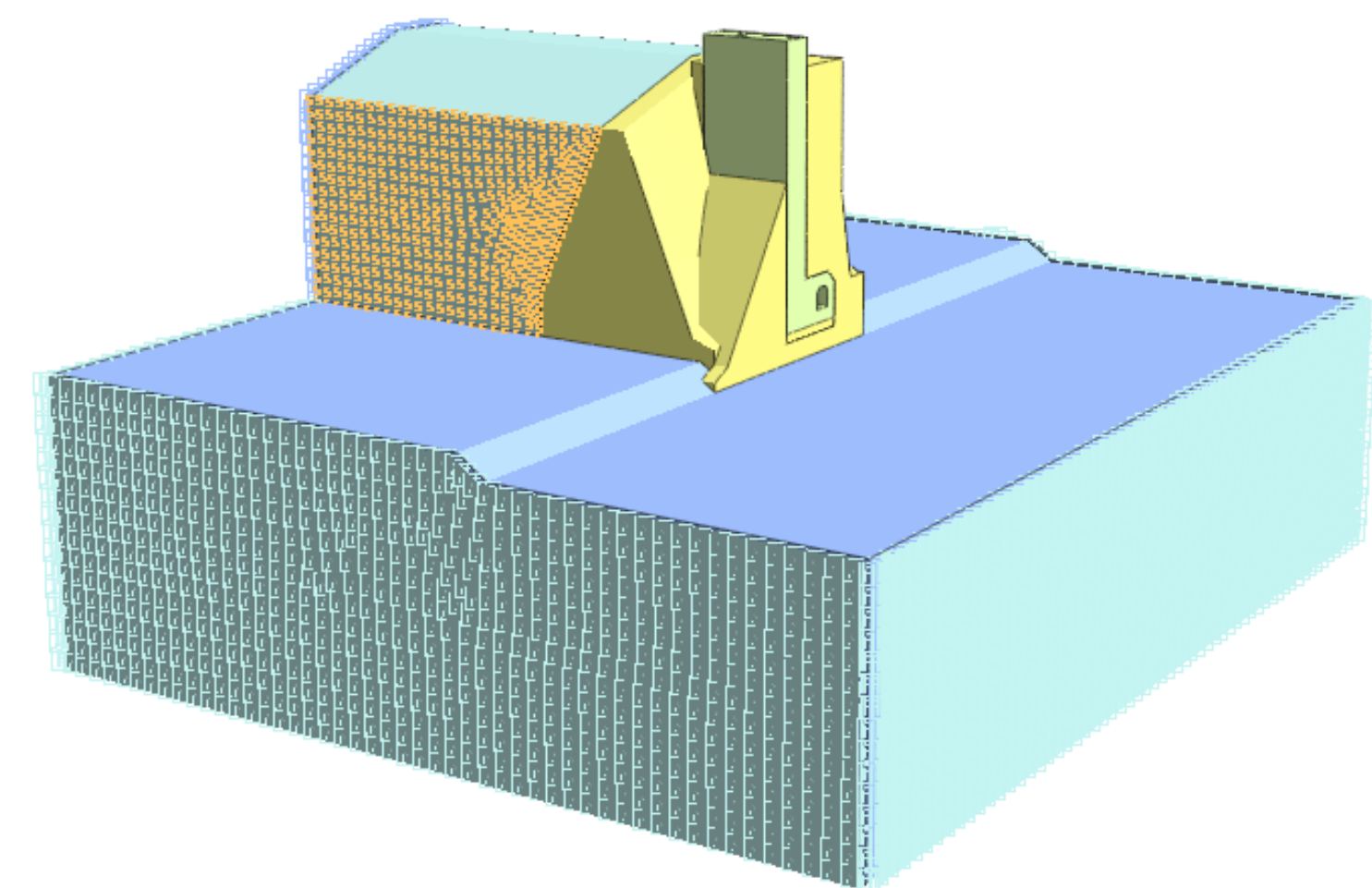
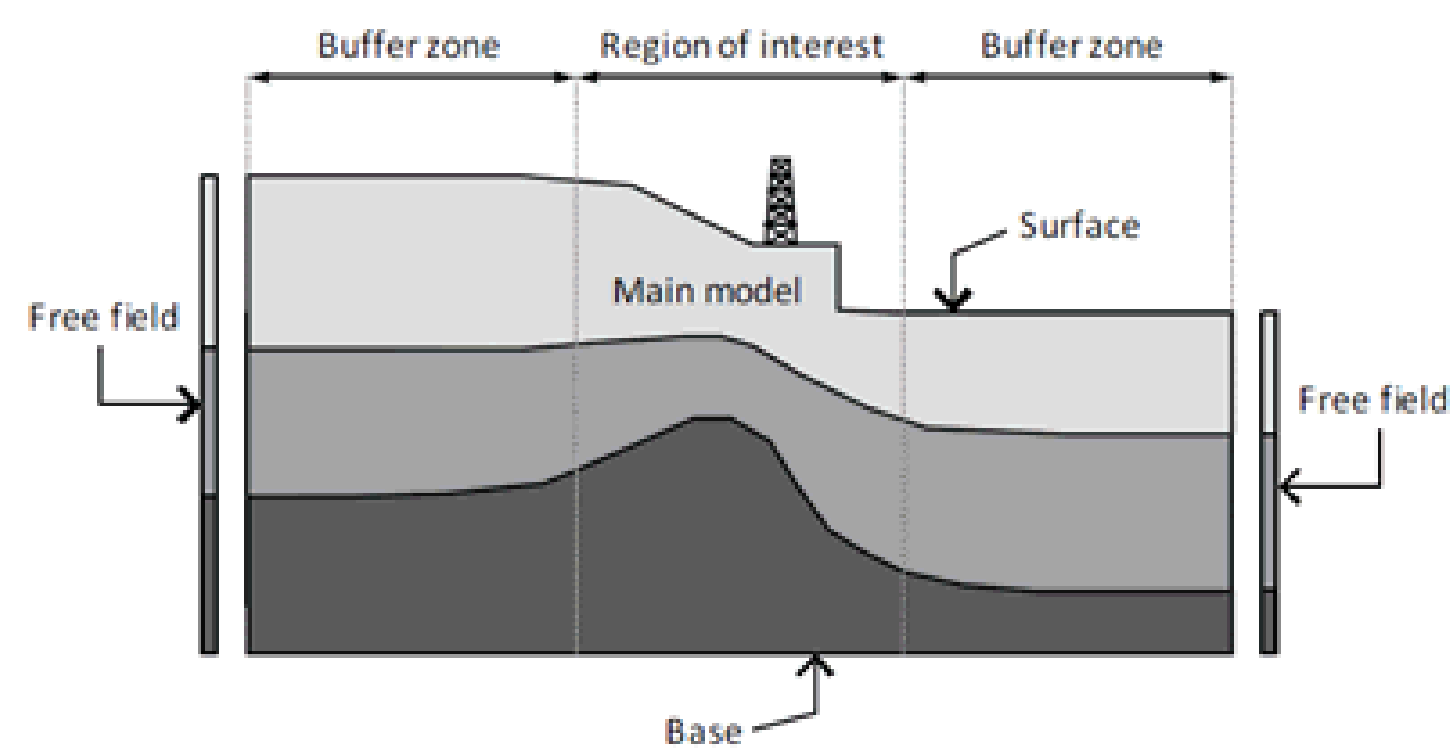
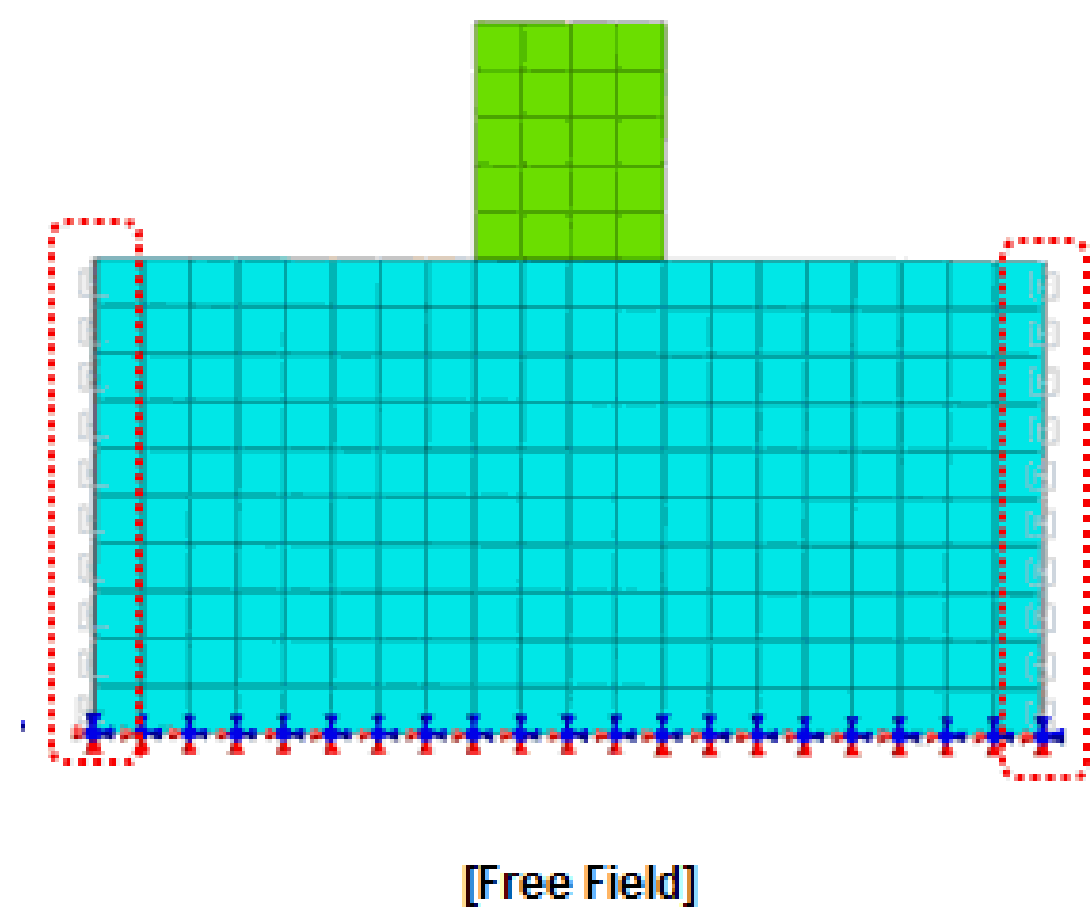
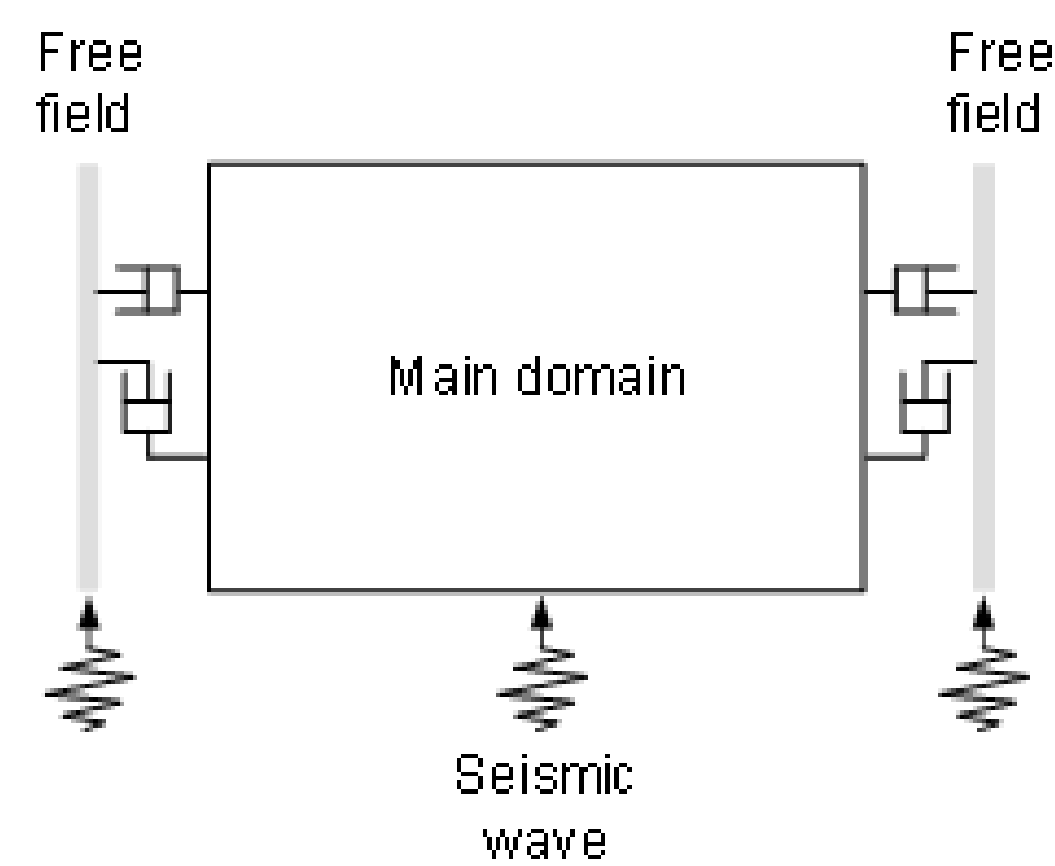
<Schematic diagram of analysis domain and FEM modeling>



Boundary Conditions

Infinite Boundaries

- 1. Free Field
- 2. Absorbent

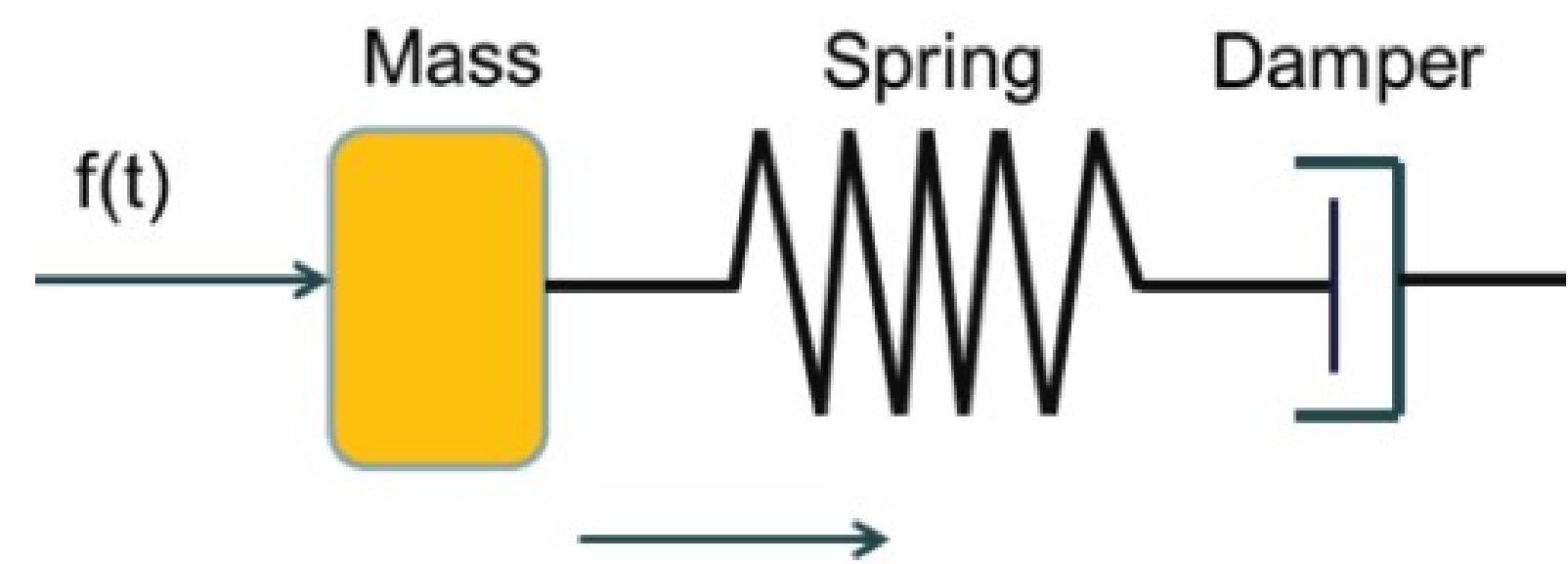


Free-Field Boundary Conditions



Boundary Conditions

Infinite Boundaries



- Modulus of subgrade reaction (Auto-calculated)

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

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

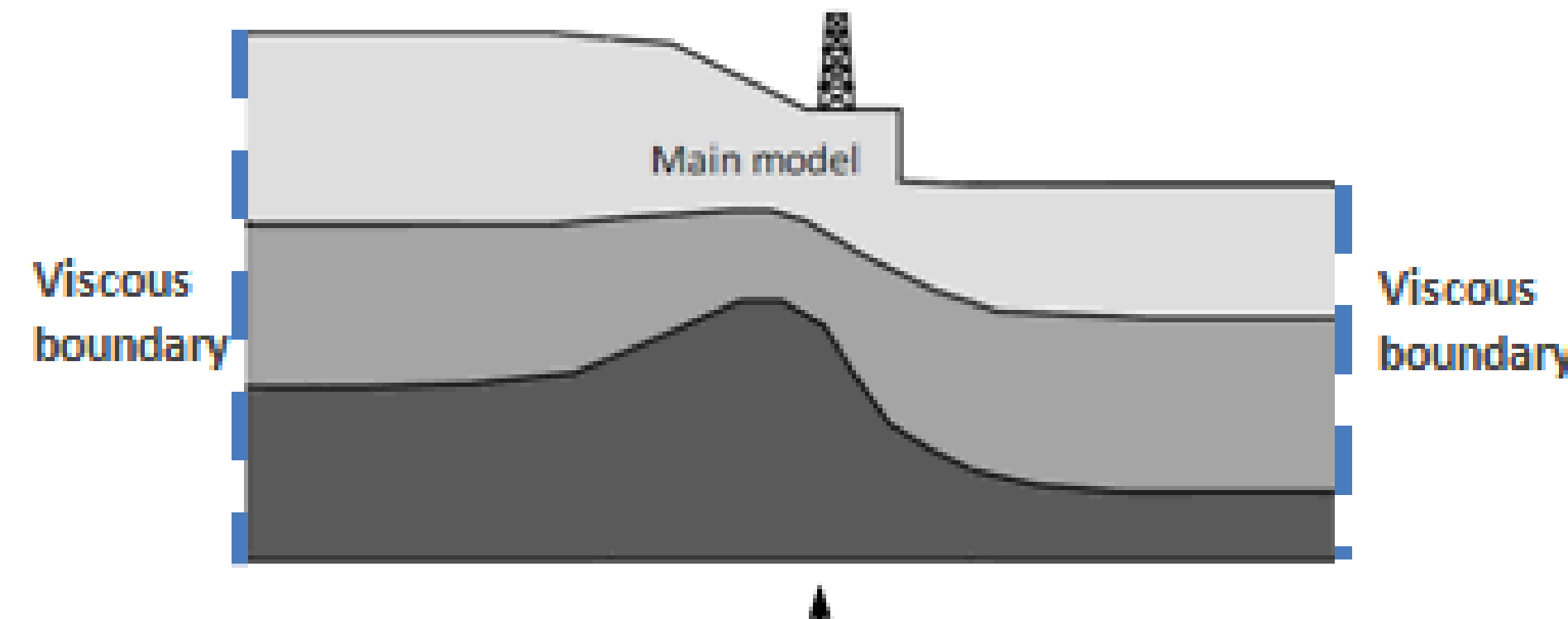
$$k_{h0} = \frac{1}{30} \alpha \cdot E_0$$

$$k_{v0} = \frac{1}{30} \alpha \cdot E_0$$

[E₀ 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 compression test	4	8
Elastic modulus from SPT using following relation (E ₀ = 28*N (tonf/m ²))	1	2

K_H : Horizontal subgrade reaction (kN/m')
K_V : Vertical subgrade reaction (kN/m')
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 = √A_h
B_v : B_v = √A_v
A_h : Horizontal area of element face (m')
A_v : Vertical area of element face (m')
α : Modulus of elasticity coefficient (From table)



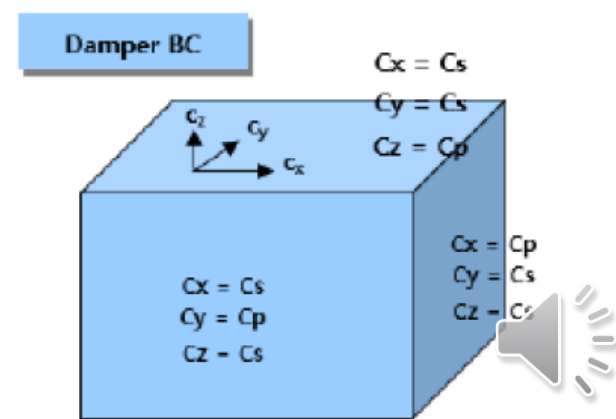
- Damping constant

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

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

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

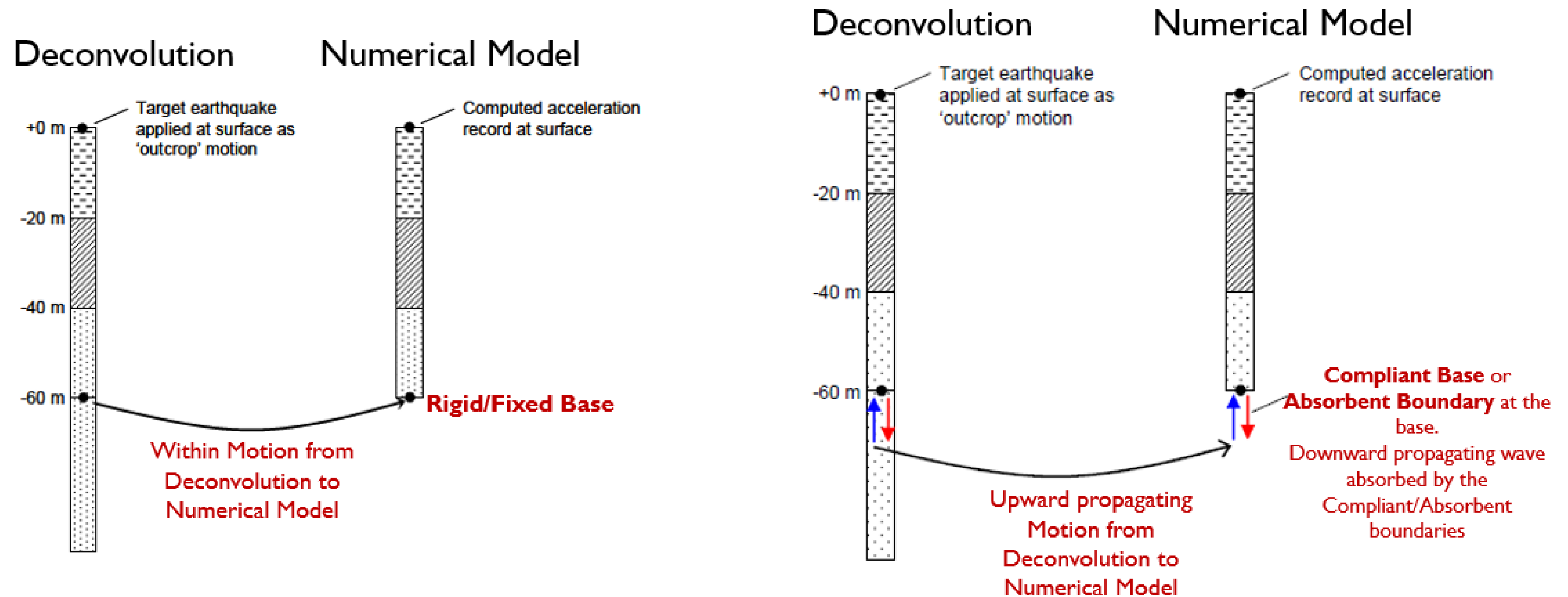
λ : Volumetric modulus (tonf/m²)
G : Shear modulus (tonf/m²)
E : Elasticity (tonf/m²)
ν : Poisson's ratio
A : Element face area (m²)



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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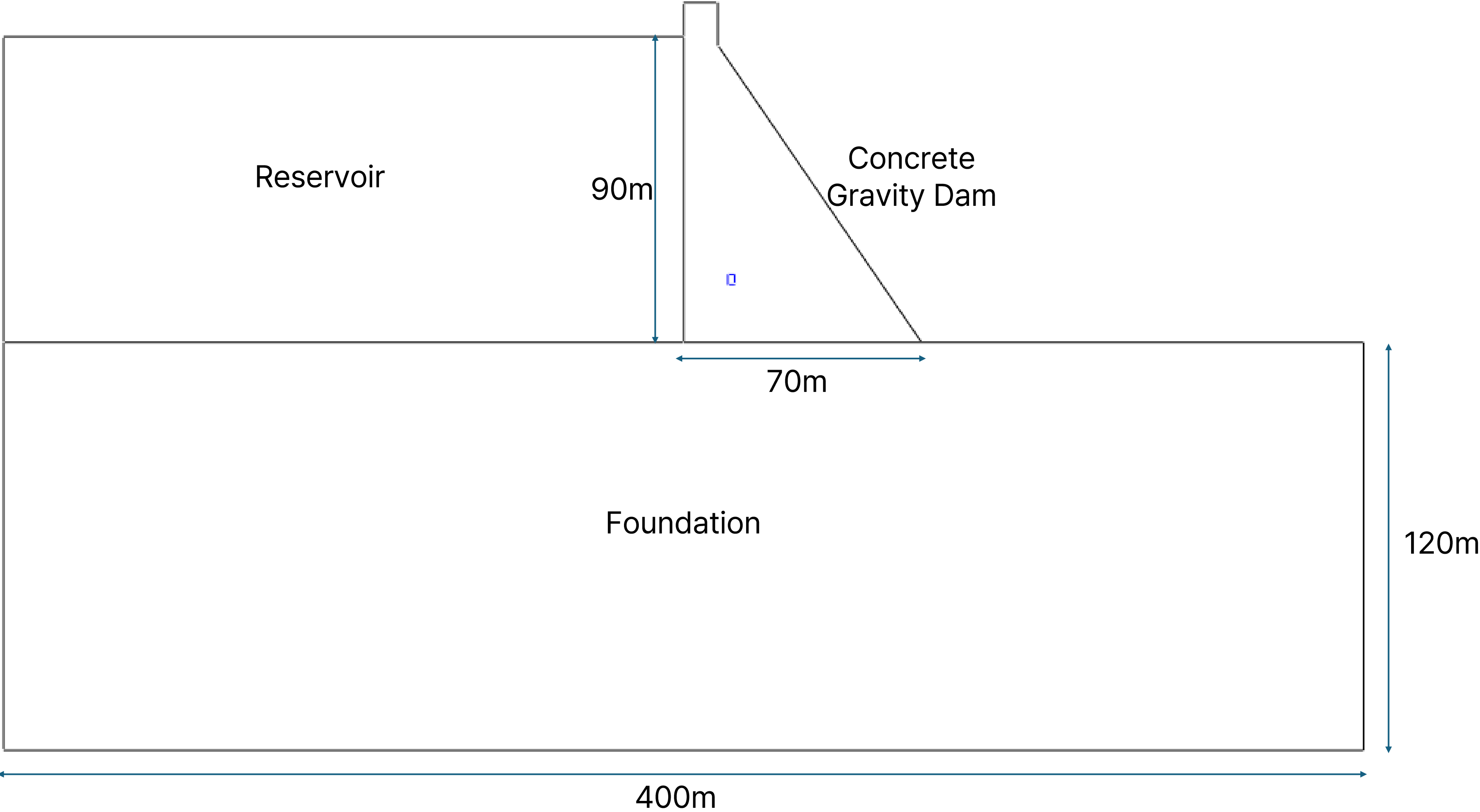
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- **Definitions for Seismic Analysis**

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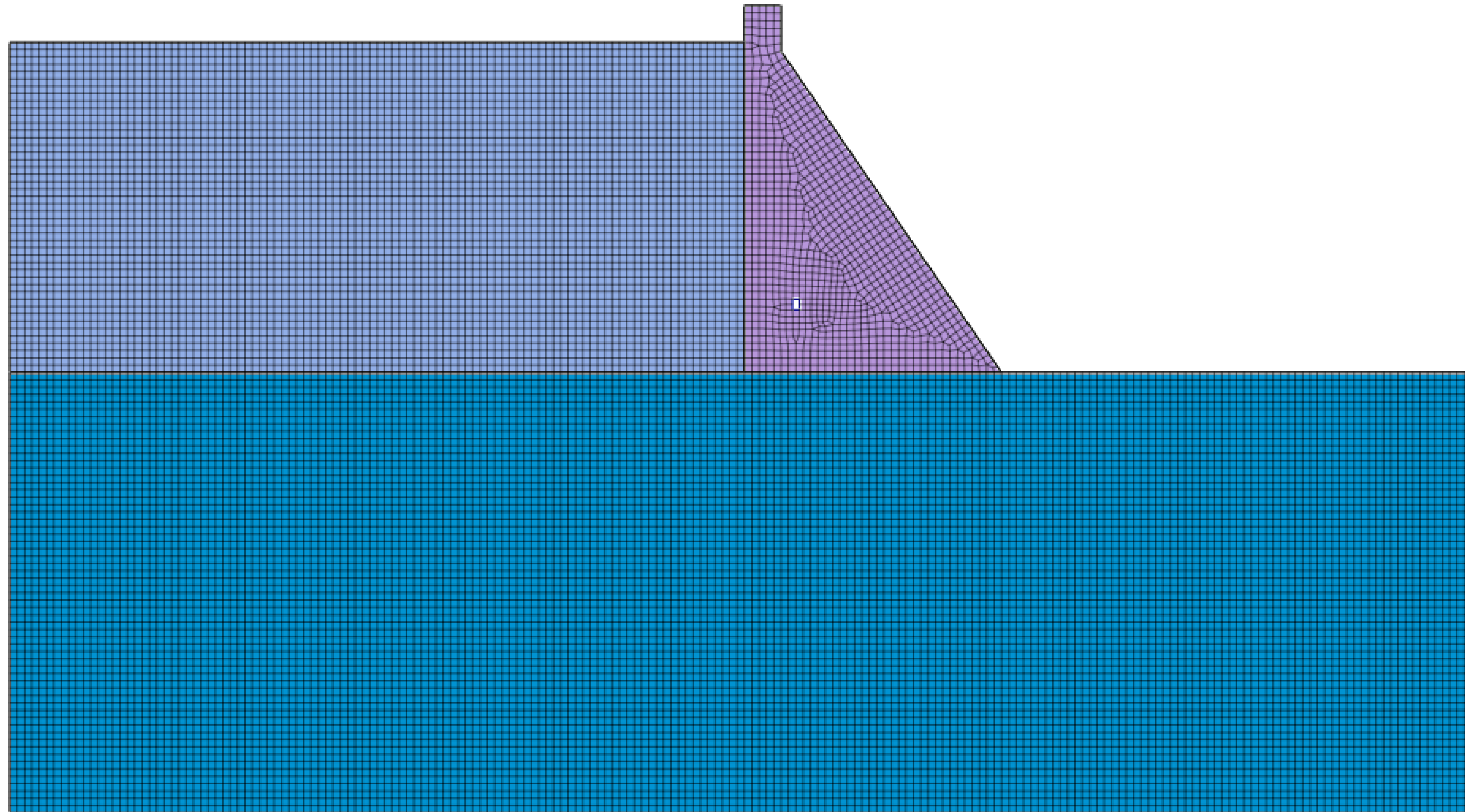
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Geometry Model



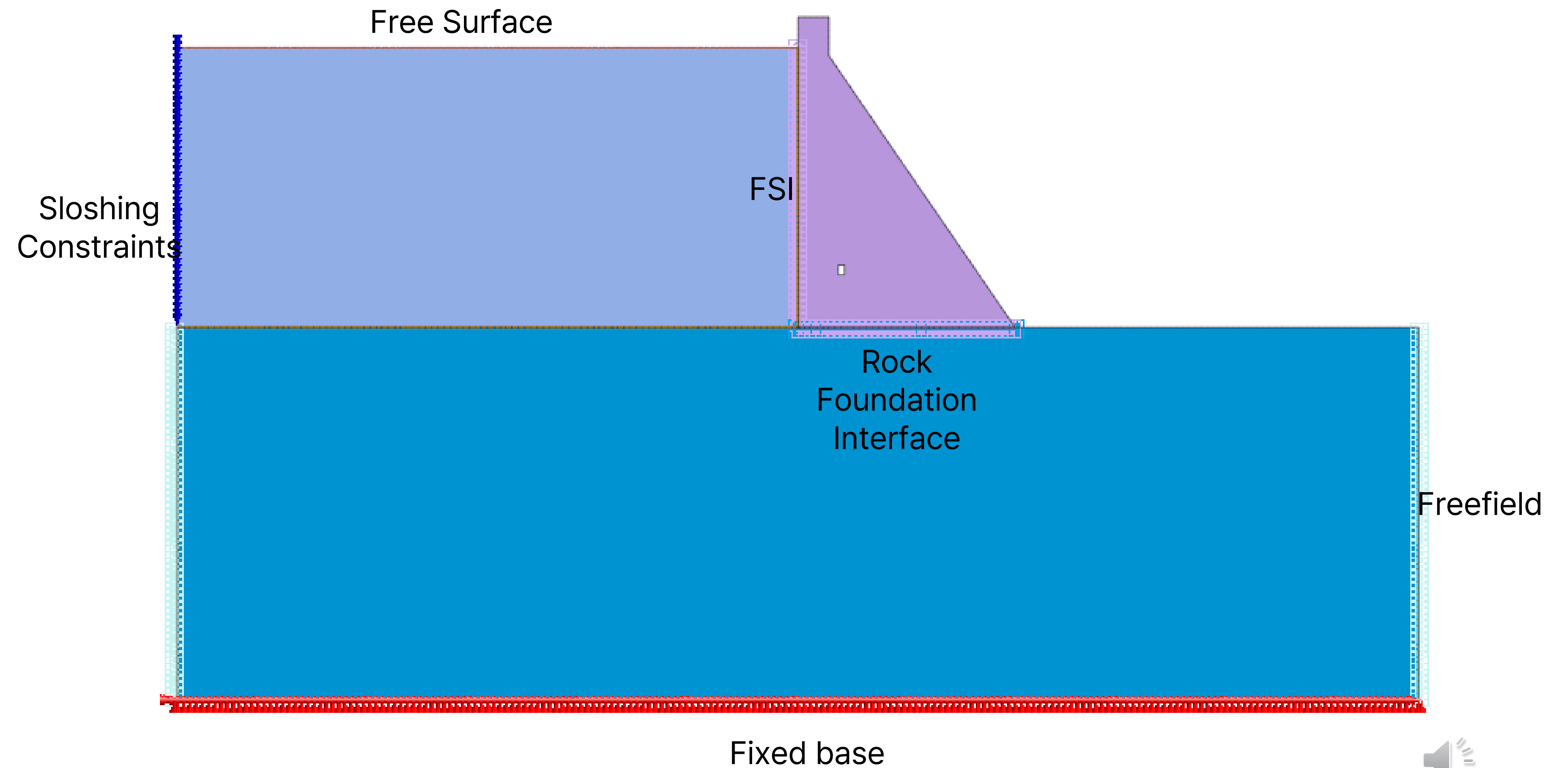
Meshing



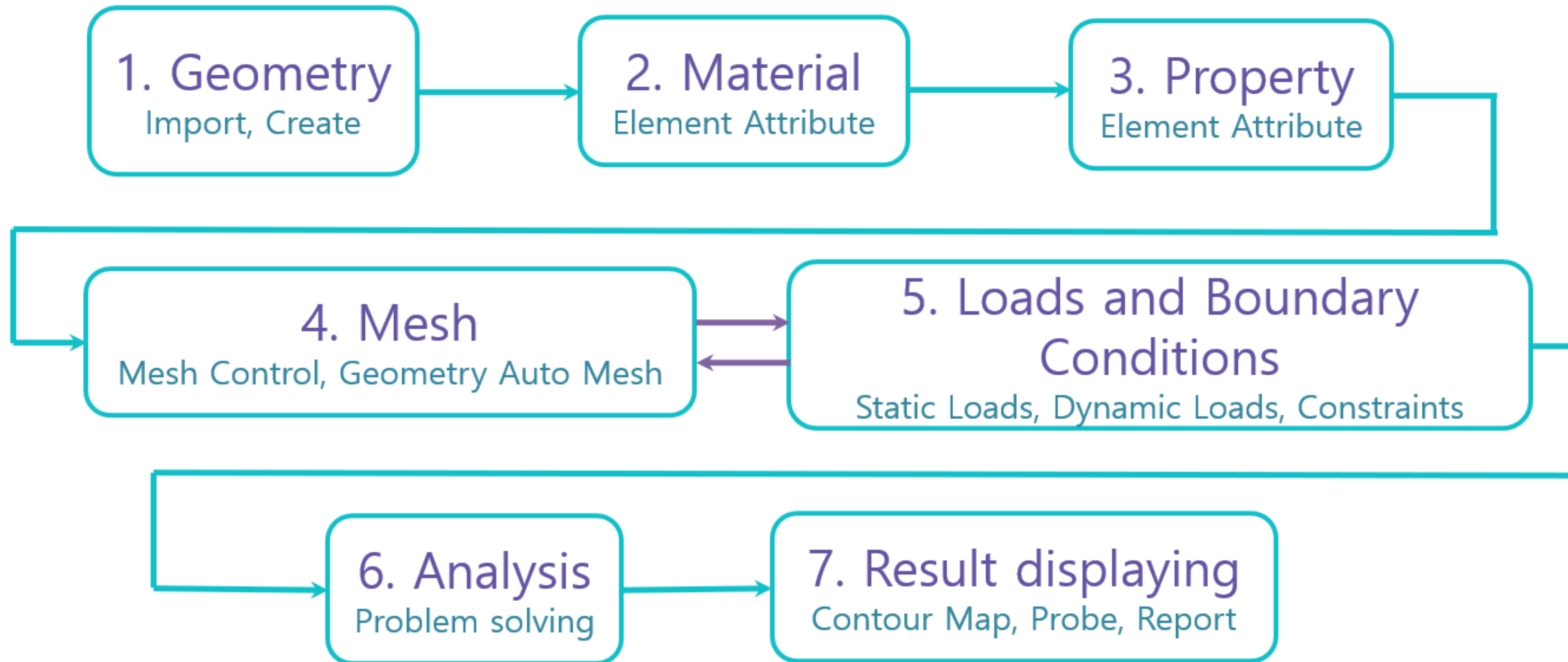
Mesh Size=2m



Boundary Conditions & FSI Definitions



General Workflow



Let's Model!!



Thanks for Attending!!