Nonlinear Analysis of Viaducts and Overpasses

Geotechnical Modeling Issues

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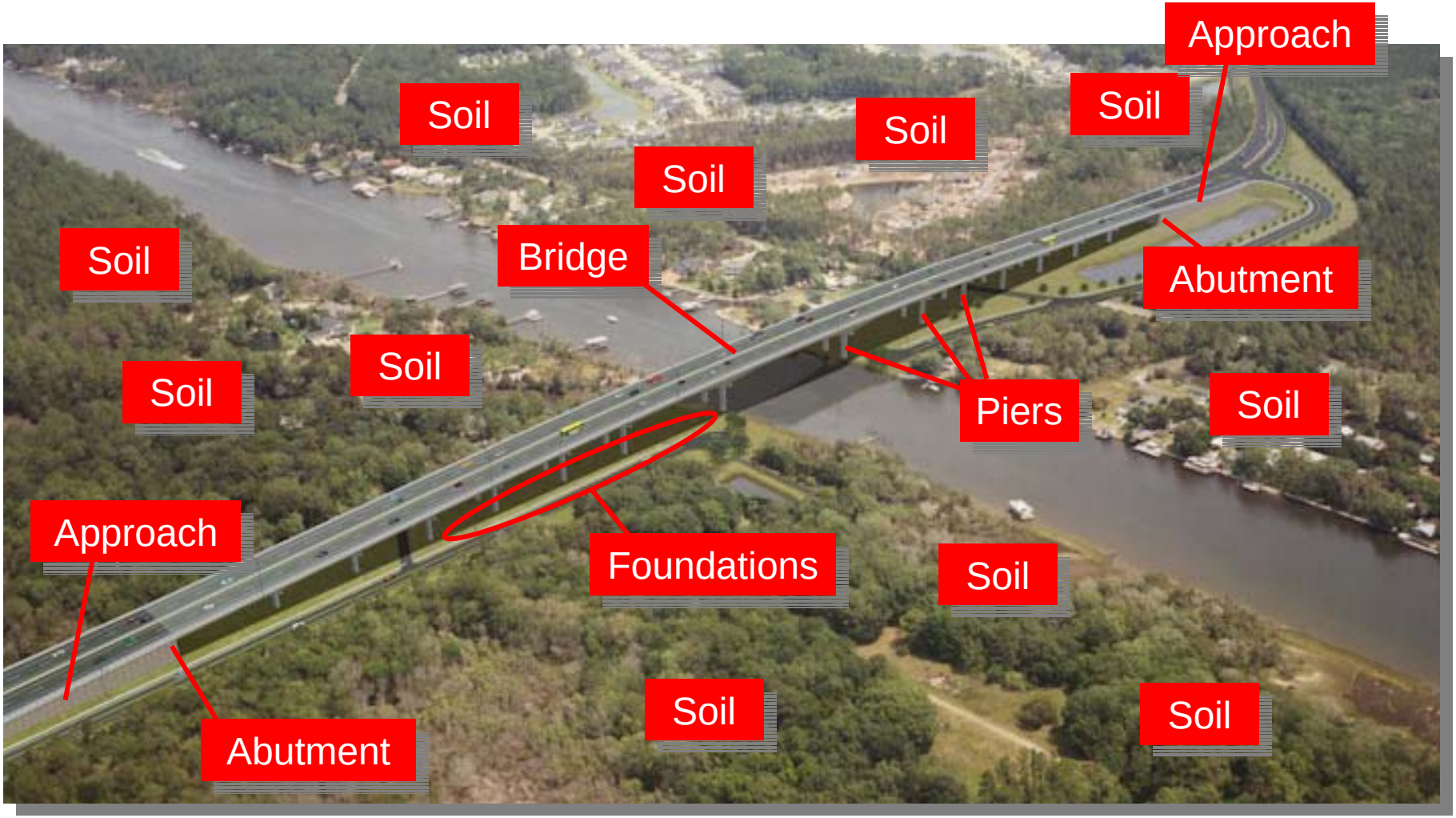
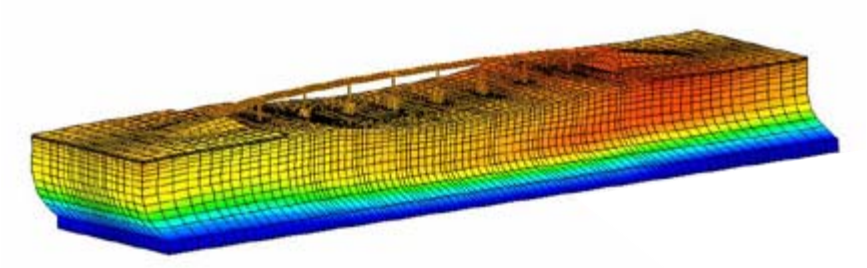
The Problem


Approach
Soil
Soil
Soil
Soil
Soil
Bridge
Abutment
Soil
Soil
Piers
Soil
Approach
Foundations
Soil
Soil
Soil
Abutment

Reality

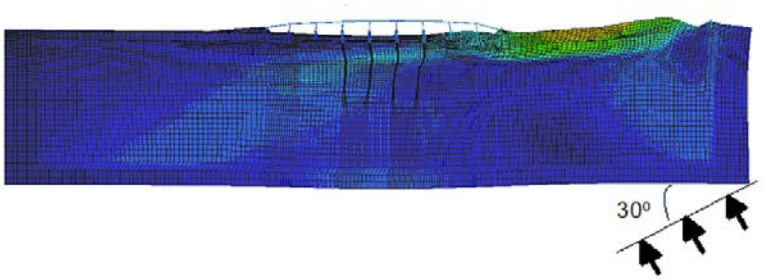
Three-dimensional problem

- Soil
- Bridge
- Motions



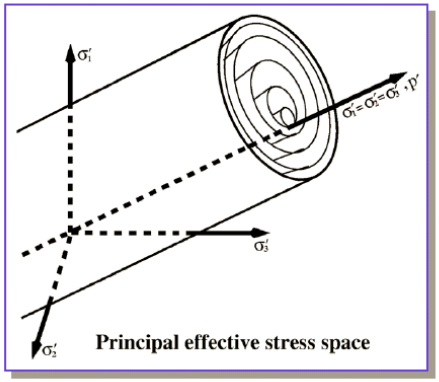
Finite extent

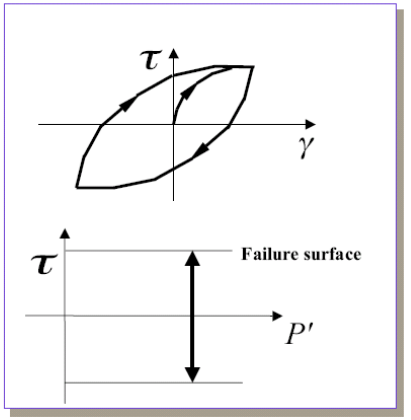
- Short structures - overpass
- Long structures - viaduct



Soil behavior

- Nonlinear, inelastic
- Spatial variability
- Quantity / quality of data





Reality

Soil-Foundation-Structure Interaction (SFSI)

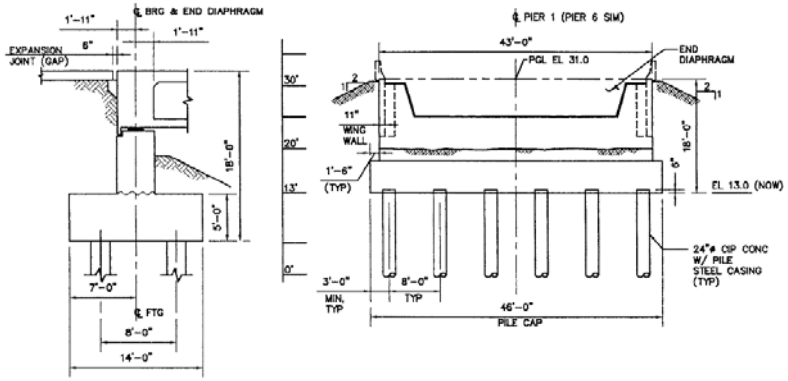
- Effects on system stiffness
- Effects on system damping
- Effects on displacements

} Shallow foundations

} Deep foundations

Abutments

- Stiffness
- Failure



Time-dependent soil behavior

- Pore pressure generation
- Pore pressure dissipation
- Delayed failure

Geotechnical Modeling Issues

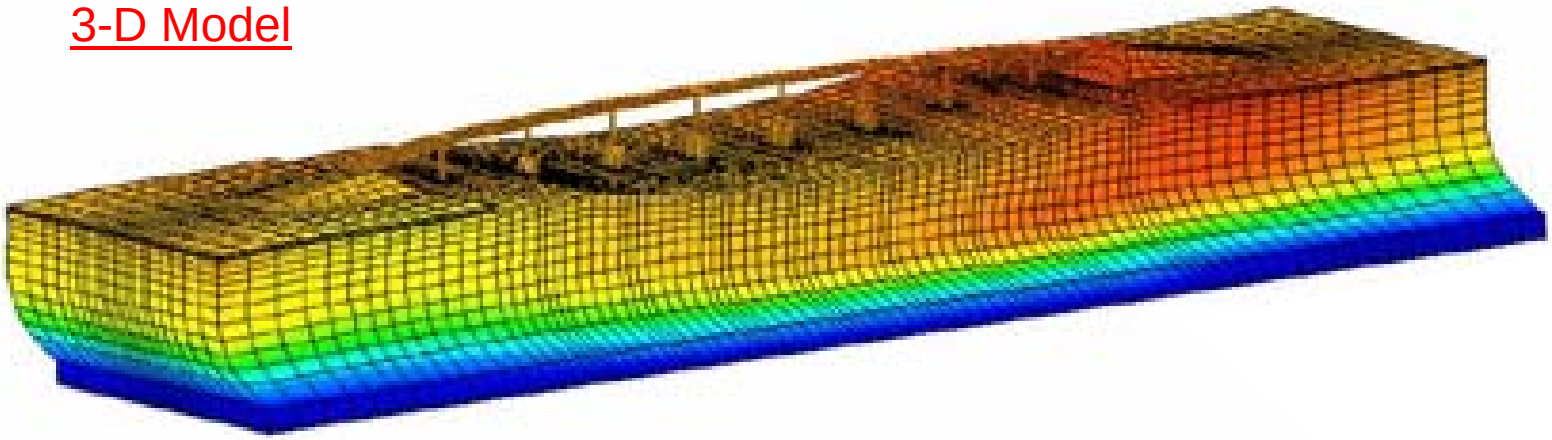
Three-dimensional problem

- Soil
- Bridge
- Motions

Three-dimensional OpenSees analyses

- **Possible using brick elements**
- **Very long run times**
- **How to handle foundations?**
  - **Continuum representation**
  - **Discrete (spring) representation**

3-D Model



Geotechnical Modeling Issues

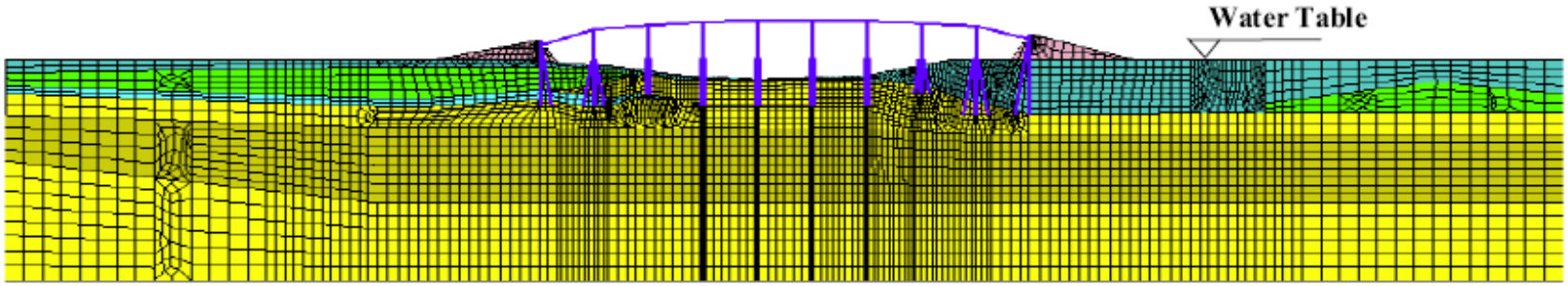
Three-dimensional problem

- Soil
- Bridge
- Motions

Two-dimensional OpenSees analyses

- **Quad elements for soil**
- **Much shorter run times**
- **Discrete (spring) representation of foundations**
- **Horizontal and vertical input motions**
- **Separate analysis for out-of-plane response**

2-D Model



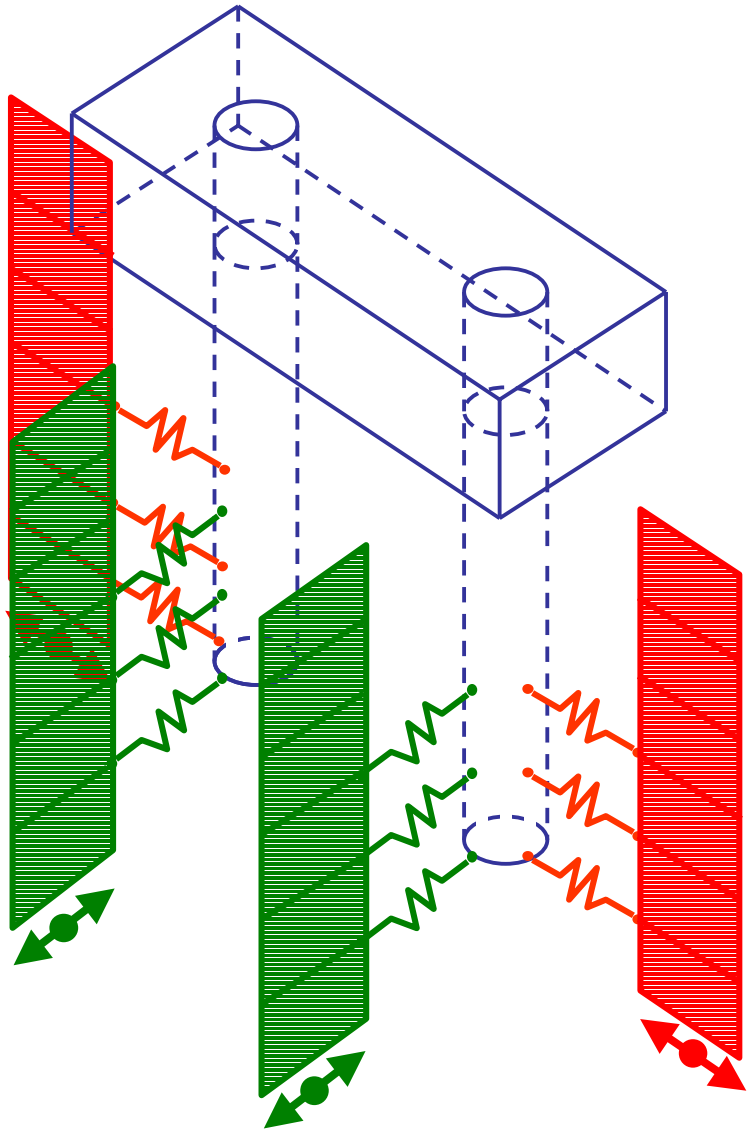
Geotechnical Modeling Issues

Three-dimensional problem

- Soil
- Bridge
- Motions

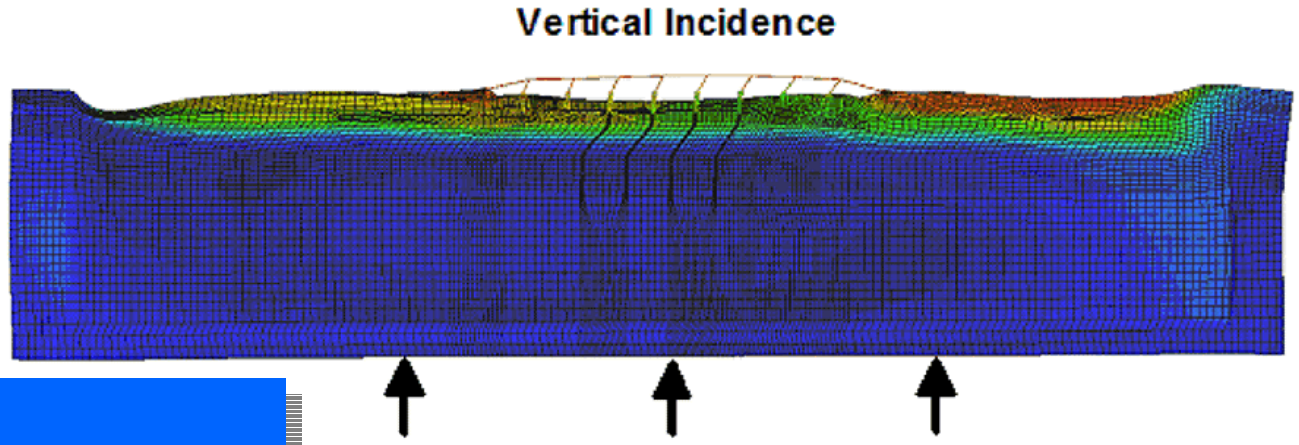
Quasi-3D OpenSees analyses

- **Perpendicular 1-D soil columns**
- **Much shorter run times**
- **Discrete (spring) representation of foundations**
- **Horizontal and vertical input motions**
- **Decoupled response at different foundation locations, and in different directions**



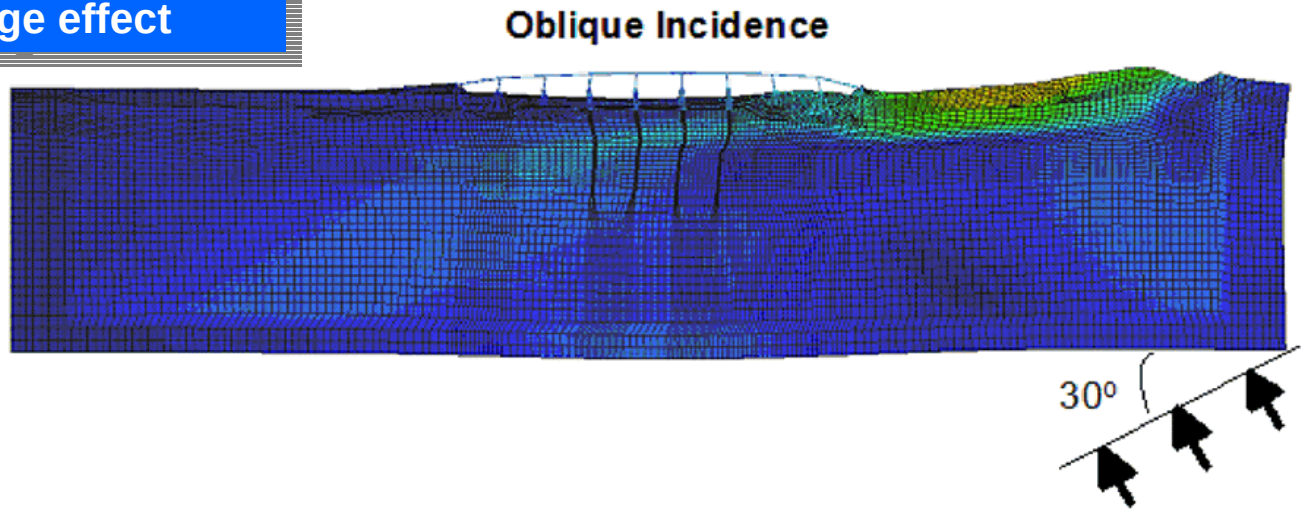
Geotechnical Modeling Issues

Finite extent – can be important for long structures



Incoherency

- **Due to variable soil conditions**
- **Due to wave passage effect**



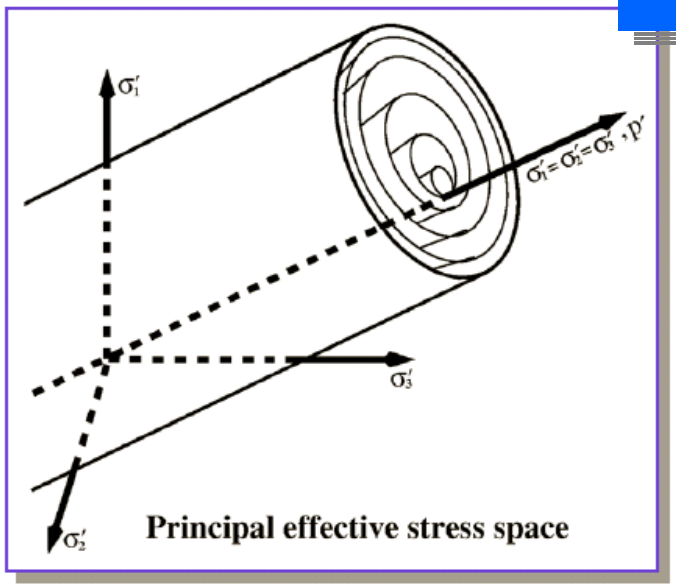
Geotechnical Modeling Issues

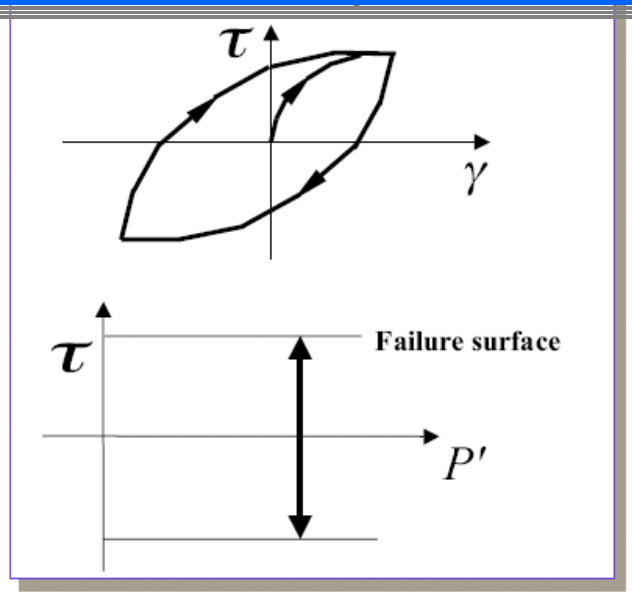
Soil behavior

- Nonlinear, inelastic
- Spatial variability
- Quantity / quality of data

Soil Models

- **Many parameters may be required**
- **Parameter identification may require numerous tests**
- **Standard parameters sets available for Elgamal models**
  - **Pressure-independent model**
  - **Pressure-dependent model**





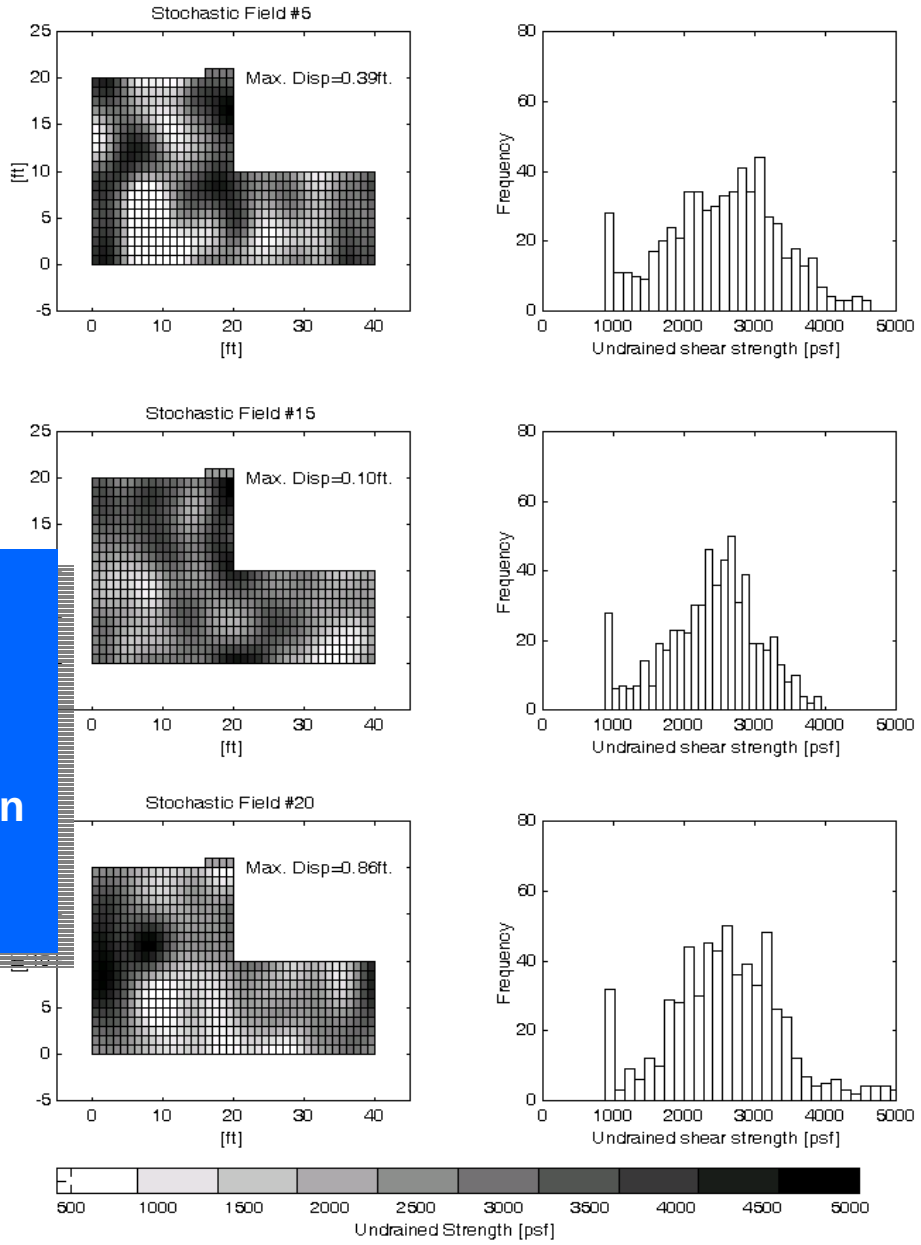
Geotechnical Modeling Issues

Soil behavior

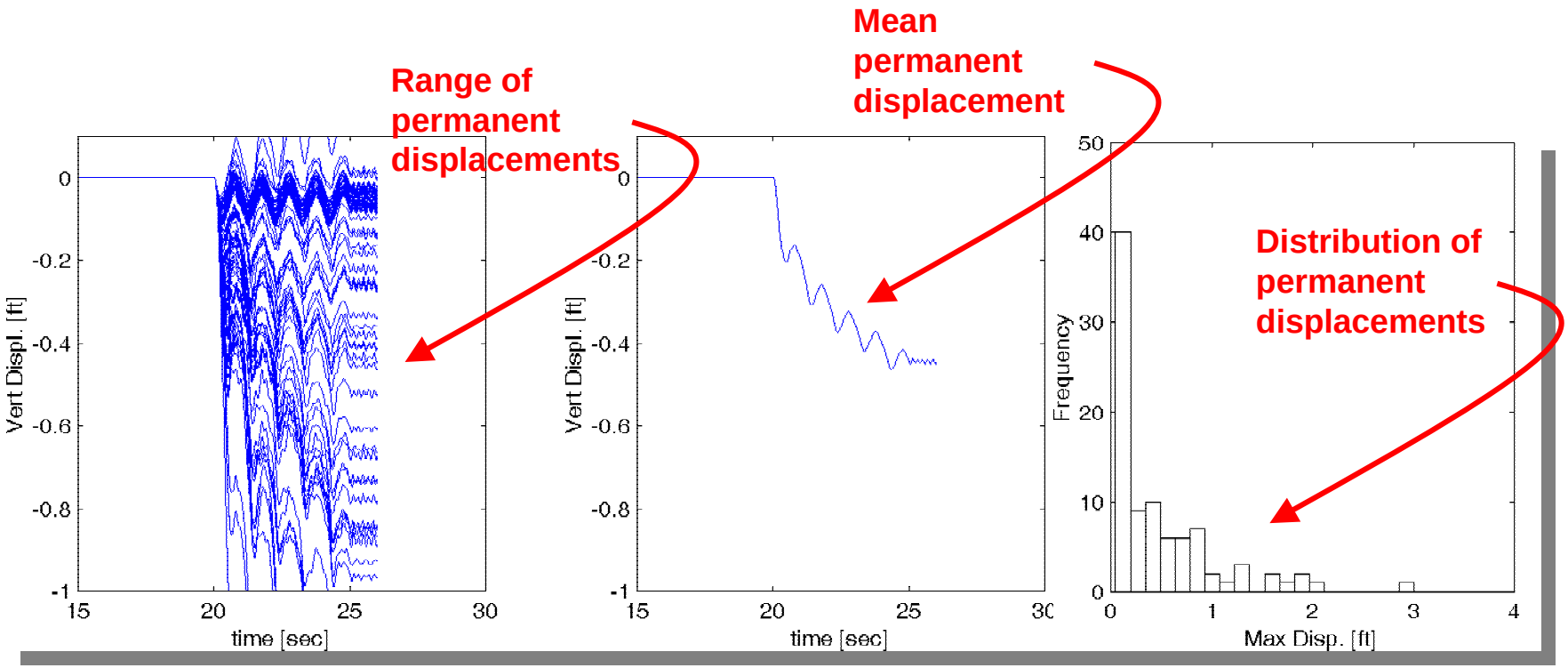
- Nonlinear, inelastic
- Spatial variability
- Quantity / quality of data

Random Fields

- **Generate multiple realizations of anticipated soil properties**
  - **Correct distribution (μ, σ)**
  - **Correct auto-correlation function**
- **Multiple analyses required**
- **May be time-consuming**



Geotechnical Modeling Issues



Geotechnical Modeling Issues

Soil behavior

- Nonlinear, inelastic
- Spatial variability
- Quantity / quality of data

Subsurface Investigation

- **Soil sampled at discrete number of locations**
- **Laboratory tests affected by many factors**
  - **Disturbance**
  - **Stress path effects**

Geotechnical Modeling Issues

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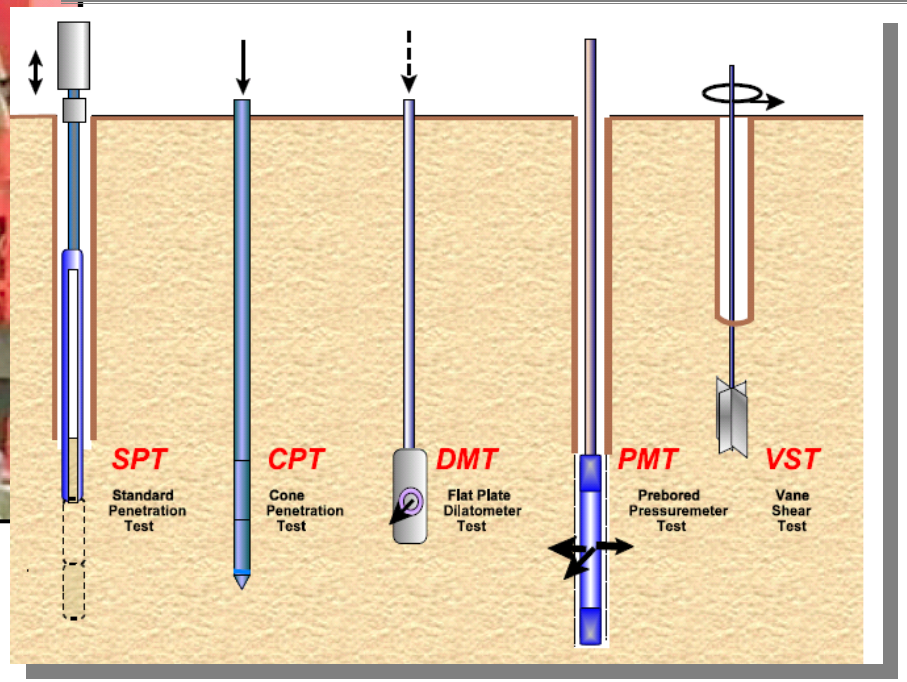

Geotechnical Modeling Issues

Soil behavior

- Nonlinear, inelastic
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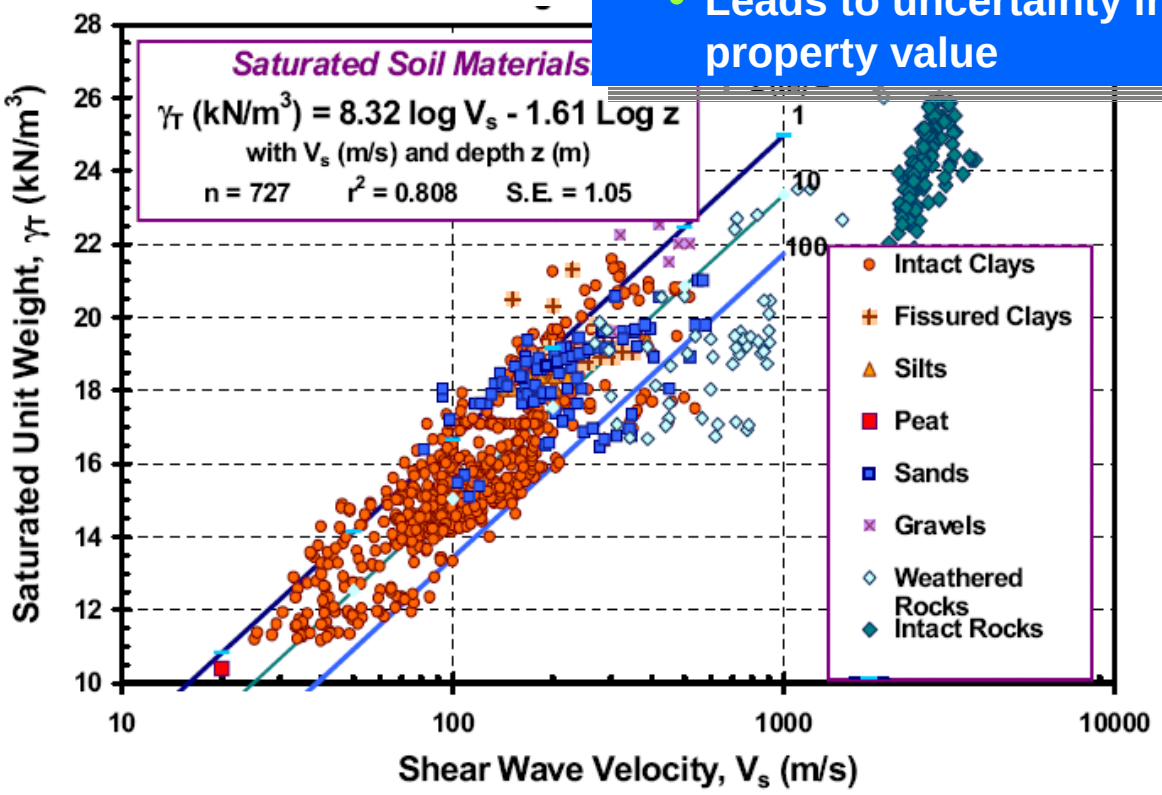
Correlations

- **Parameter measured in insitu test correlated to property of interest**
- **Correlations available, but based on scattered data**
- **Leads to uncertainty in estimated property value**



Geotechnical Modeling Issues

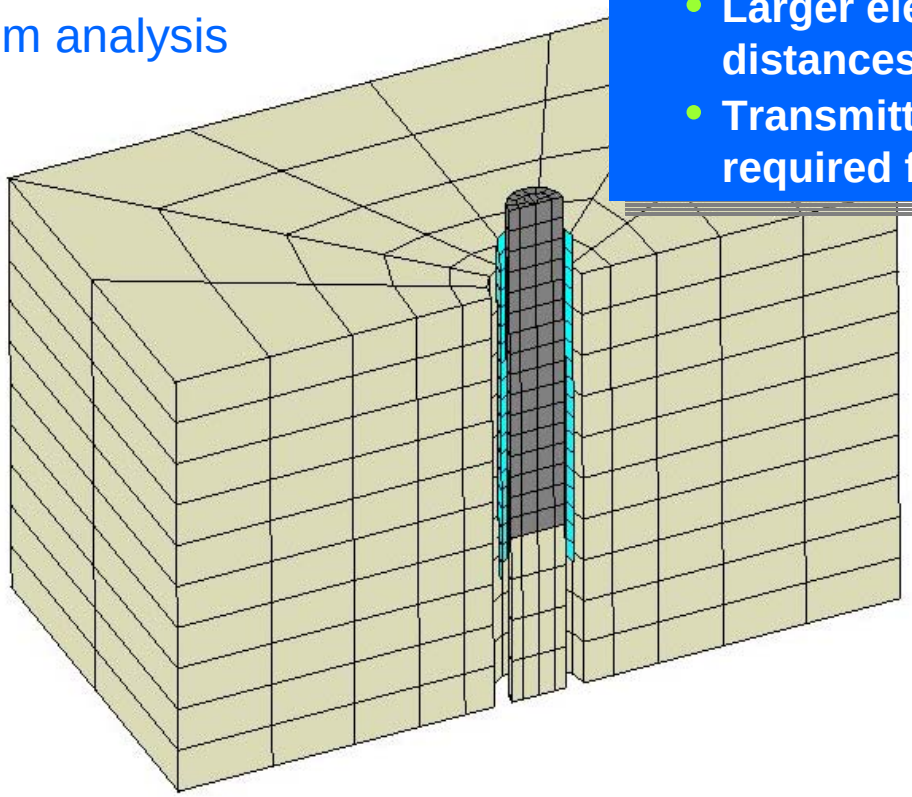
Soil-Foundation-Structure Interaction

- Shallow foundations
- Deep foundations

3-D modeling

- **Small elements required in near-field**
- **Interface elements required**
  - **Sliding**
  - **Gapping**
- **Larger elements OK at greater distances**
- **Transmitting boundaries required for radiation damping**

Continuum analysis



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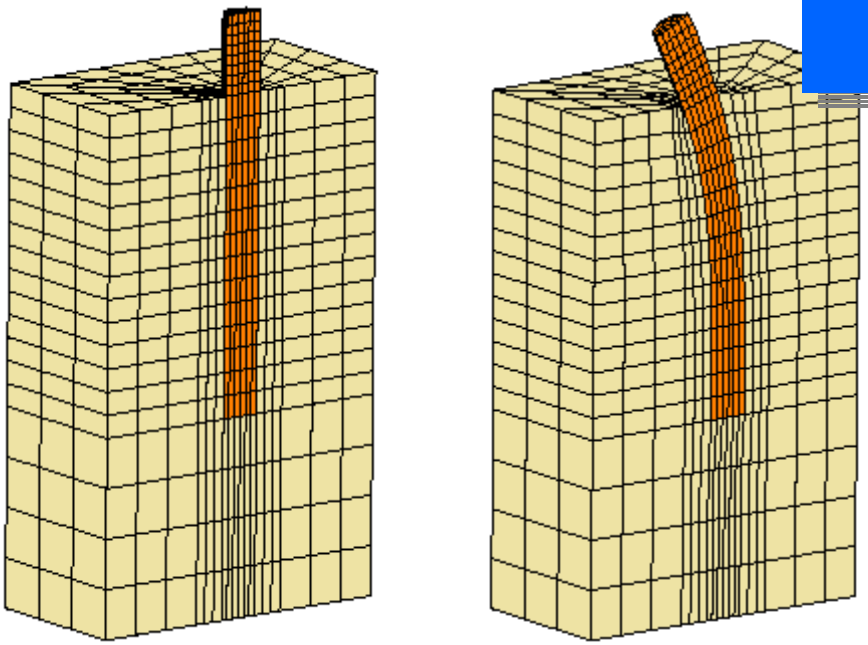

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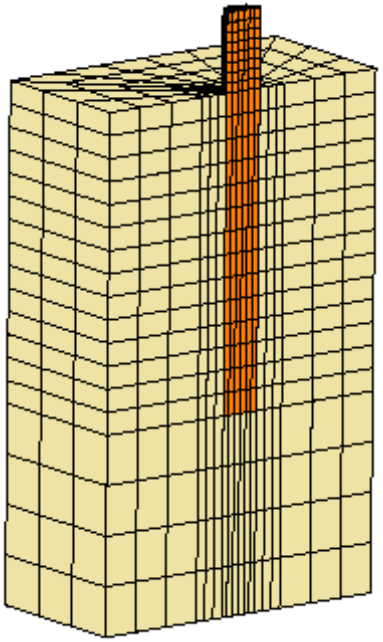

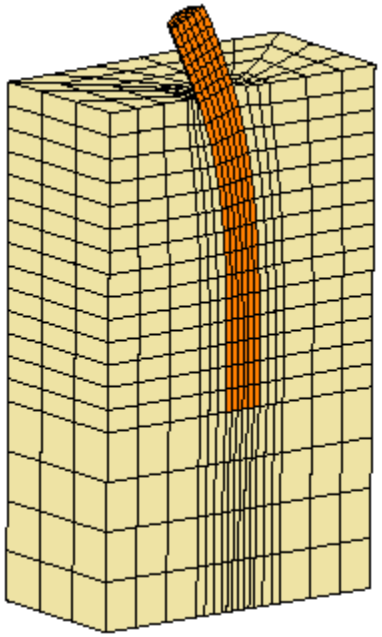

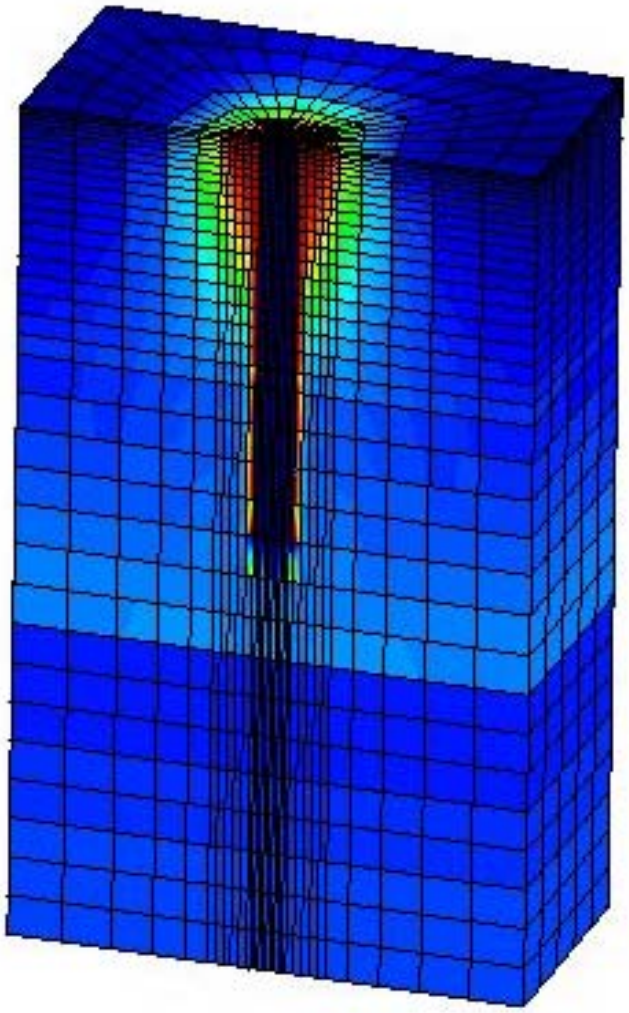

Geotechnical Modeling Issues

Soil-Foundation-Structure Interaction

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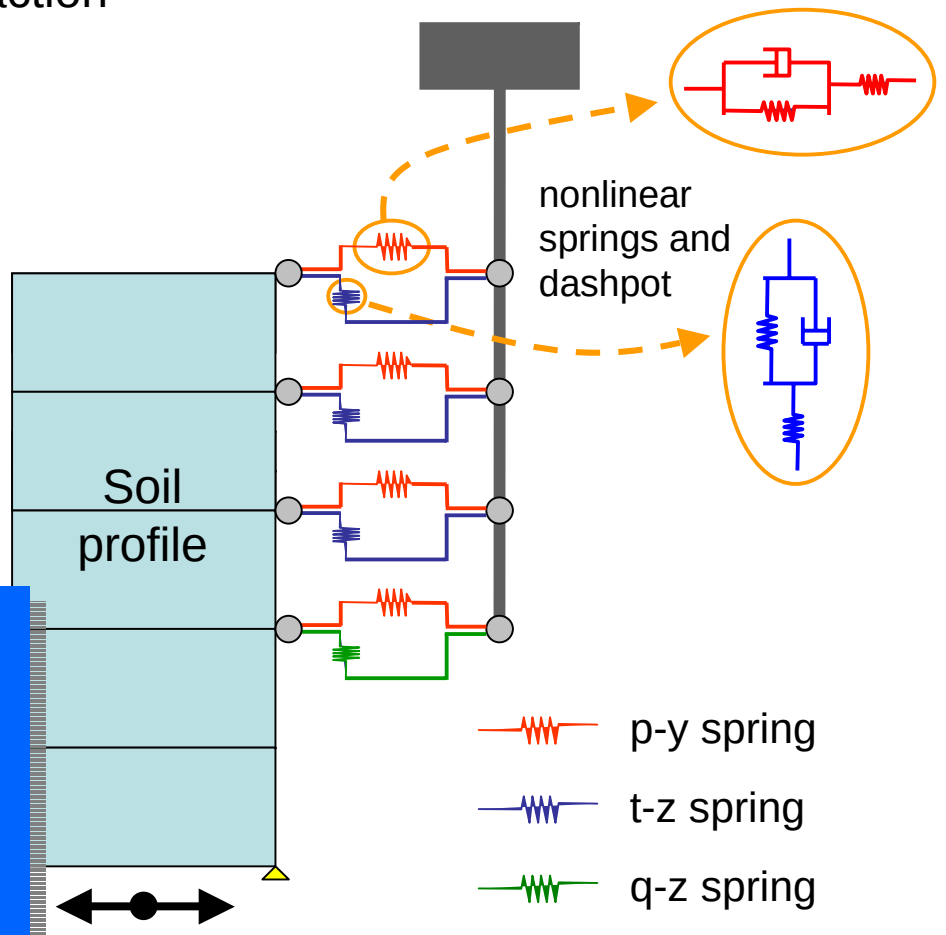
- Deep foundations

Discrete analysis



Discrete interaction elements

- **Springs to represent soil stiffness**
- **Dashpots to represent damping**
  - **Hysteretic damping in near-field**
  - **Radiation damping in far-field**
- **Must account for gapping**
- **Must account for pore pressure effects**

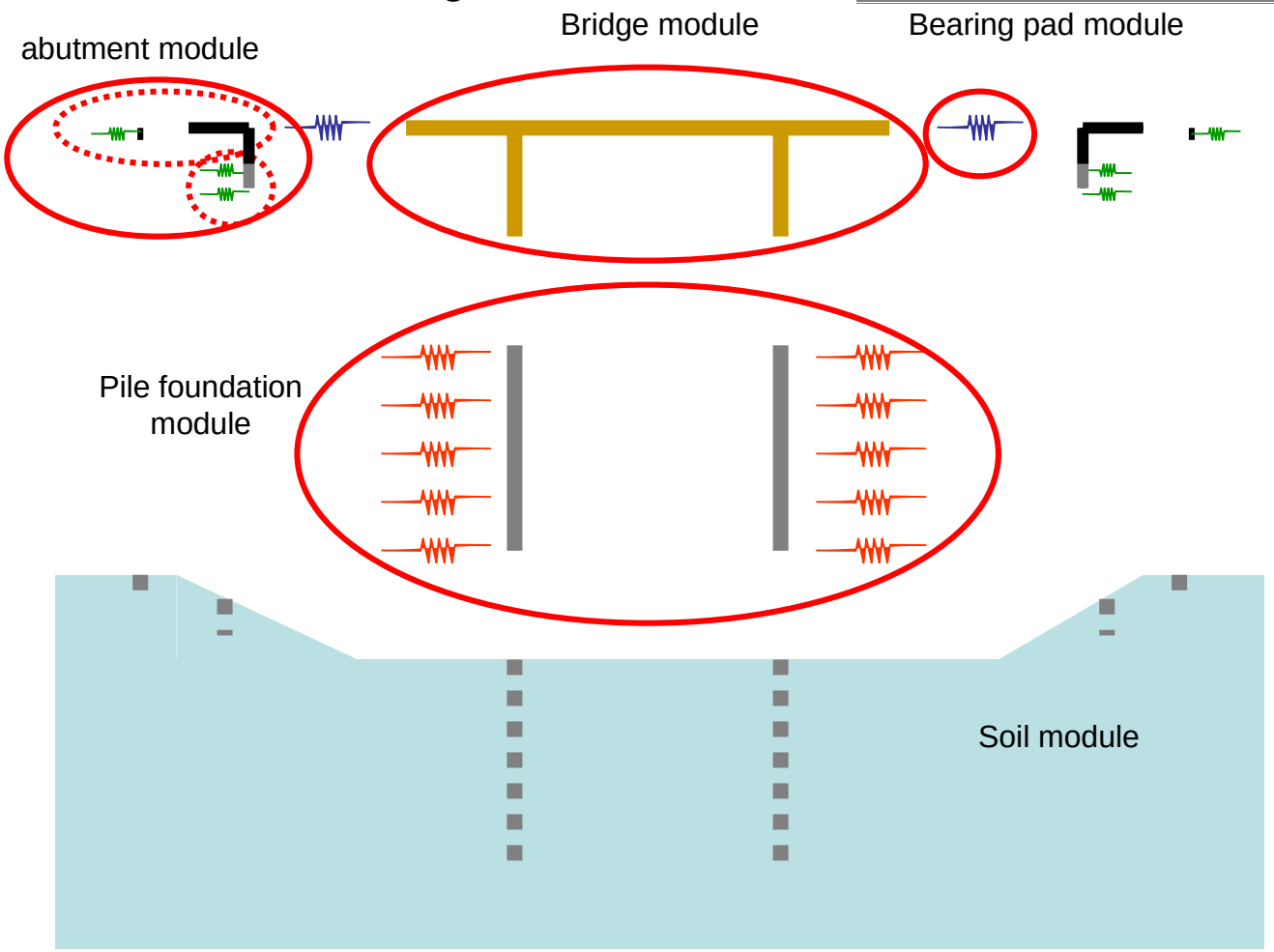
Geotechnical Modeling Issues

Discrete interaction elements

- **Nonlinear springs**
  - **Stiffness**
  - **Strength**
- **Interface elements**
- **Bearing elements**

Abutment models

- Stiffness modeling



Geotechnical Modeling Issues

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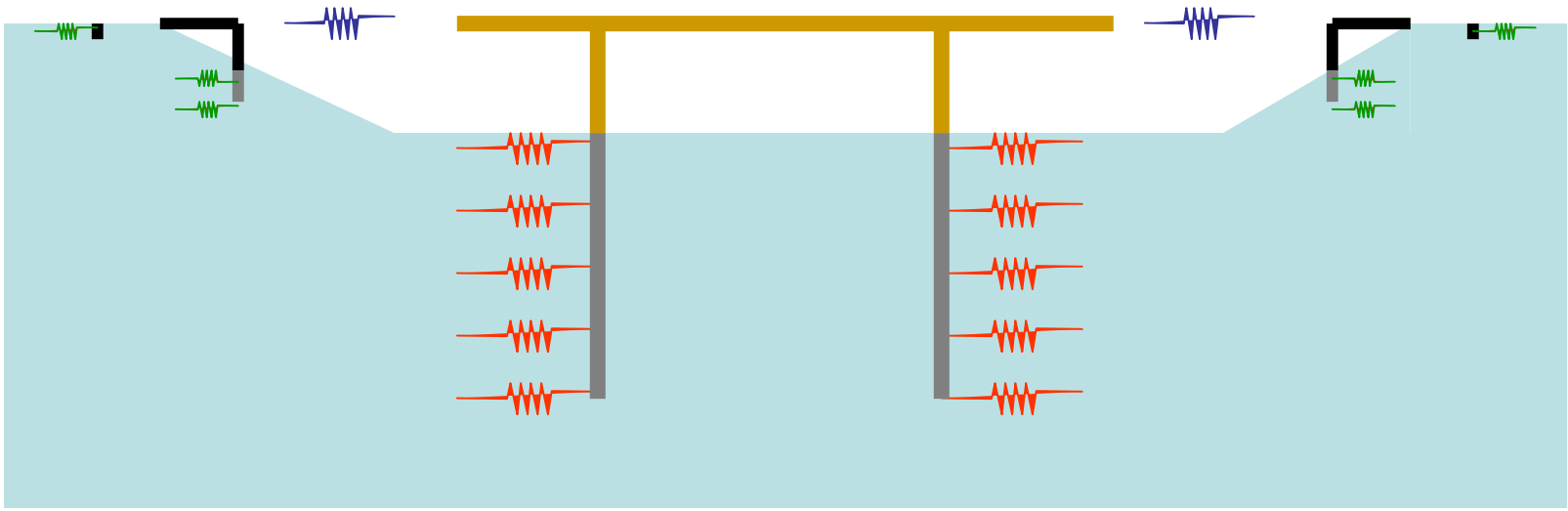

Geotechnical Modeling Issues

Abutment models

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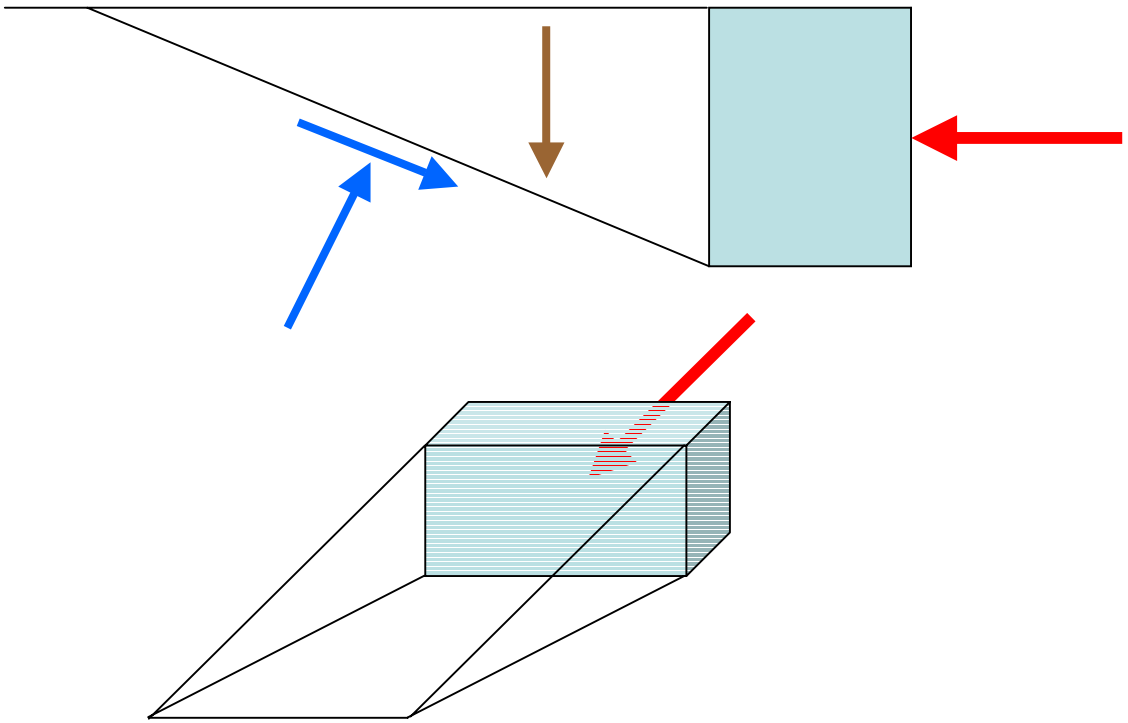

Geotechnical Modeling Issues

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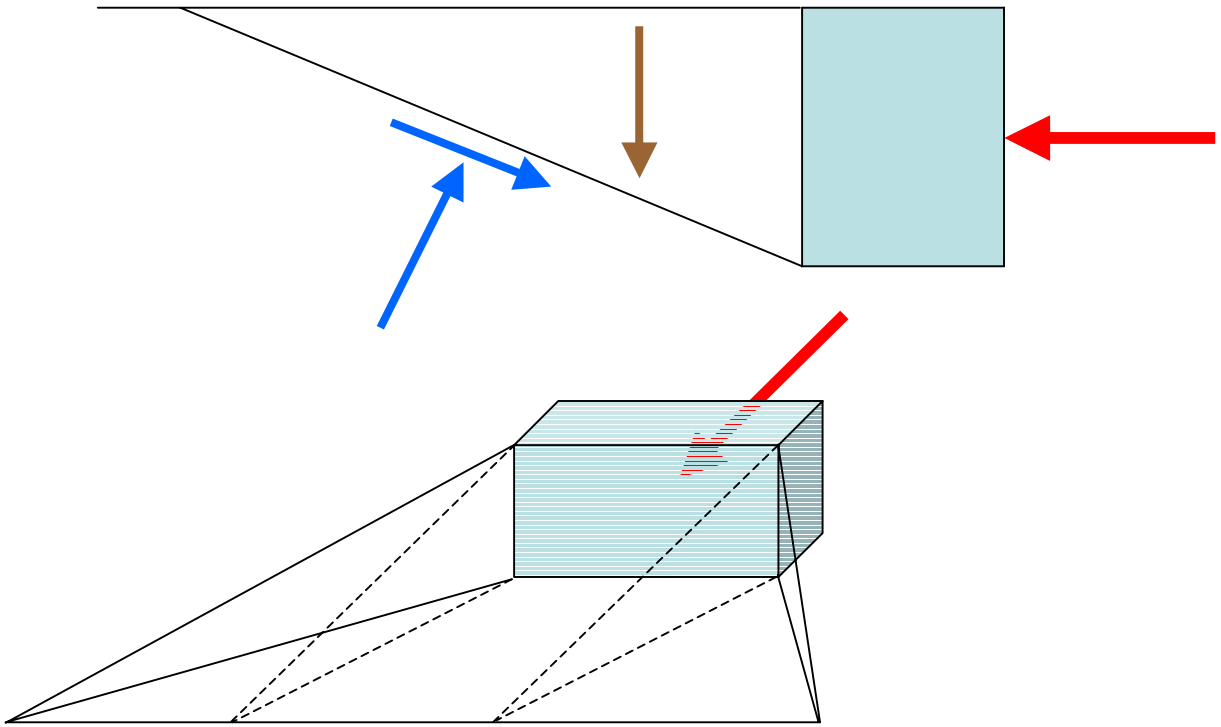

Geotechnical Modeling Issues

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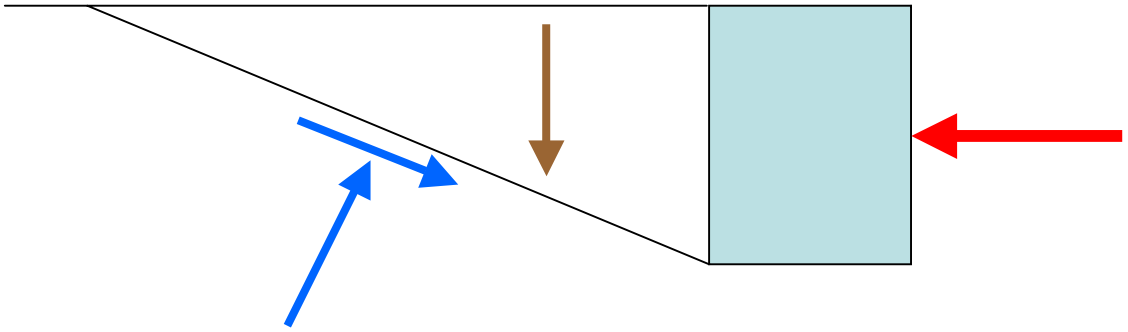
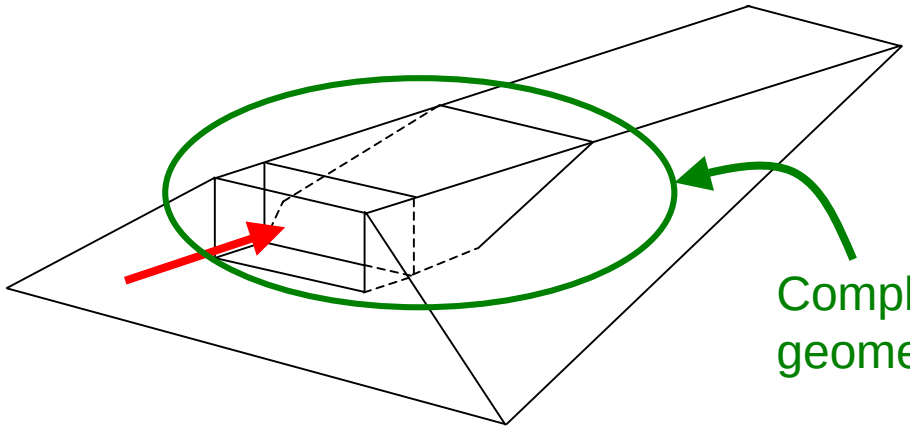




Complex failure surface geometry

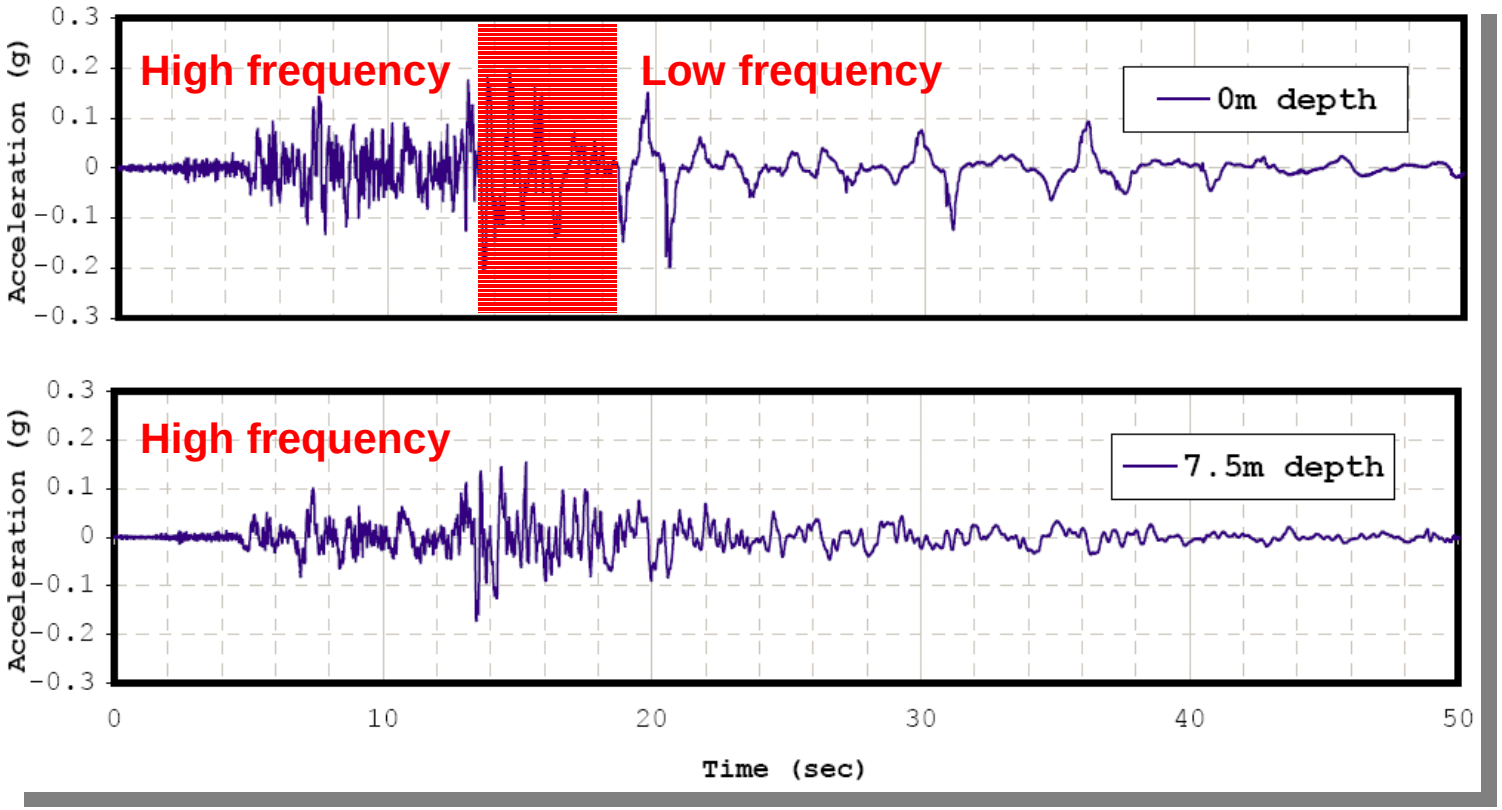
Geotechnical Modeling Issues

Time-dependent soil behavior

- Pore pressure generation
- Pore pressure redistribution
- Pore pressure dissipation

Effective stress analysis

- **Constitutive model**
  - **Modulus degradation**
  - **Phase transformation**
  - **Hysteretic damping**



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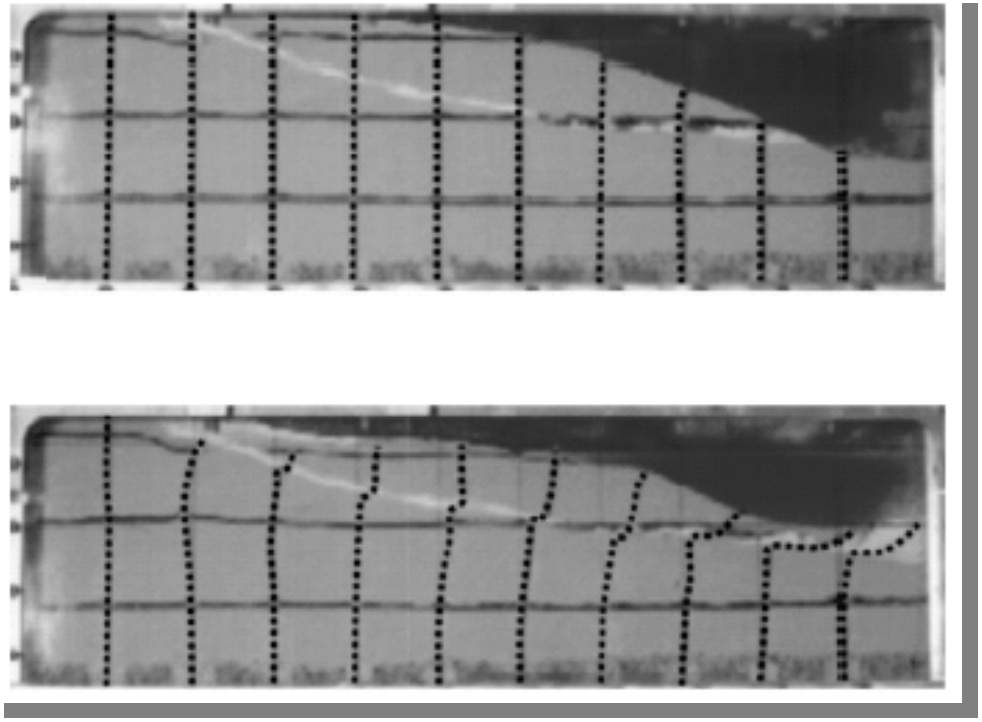
- **Diffusion equation solution**



Geotechnical Modeling Issues

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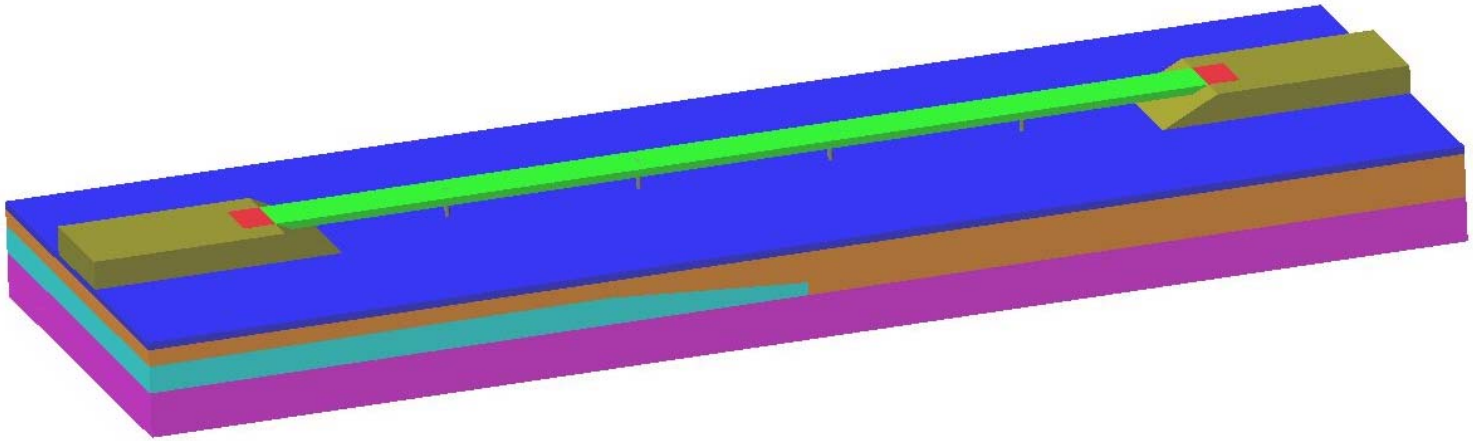
Effective stress analysis

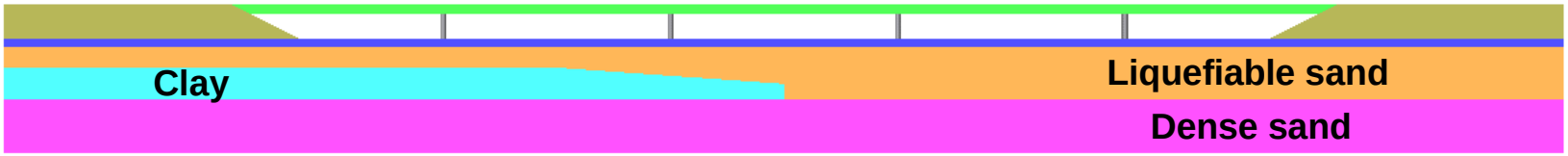
- **Constitutive model**
  - **Modulus degradation**
  - **Phase transformation**
  - **Hysteretic damping**
- **Diffusion equation solution**
- **Post-liquefaction settlement**

Geotechnical Modeling - Example

Example: Bridge on liquefiable soil deposit

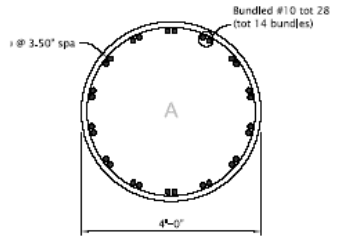
- Five-span bridge
- Approach embankments
- Variable thickness of liquefiable soil



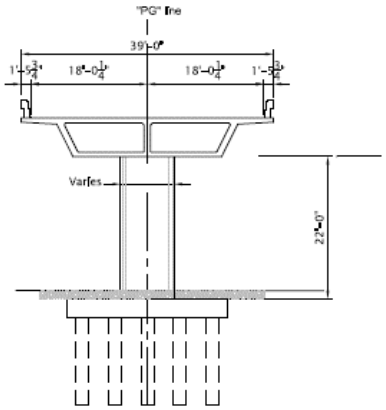


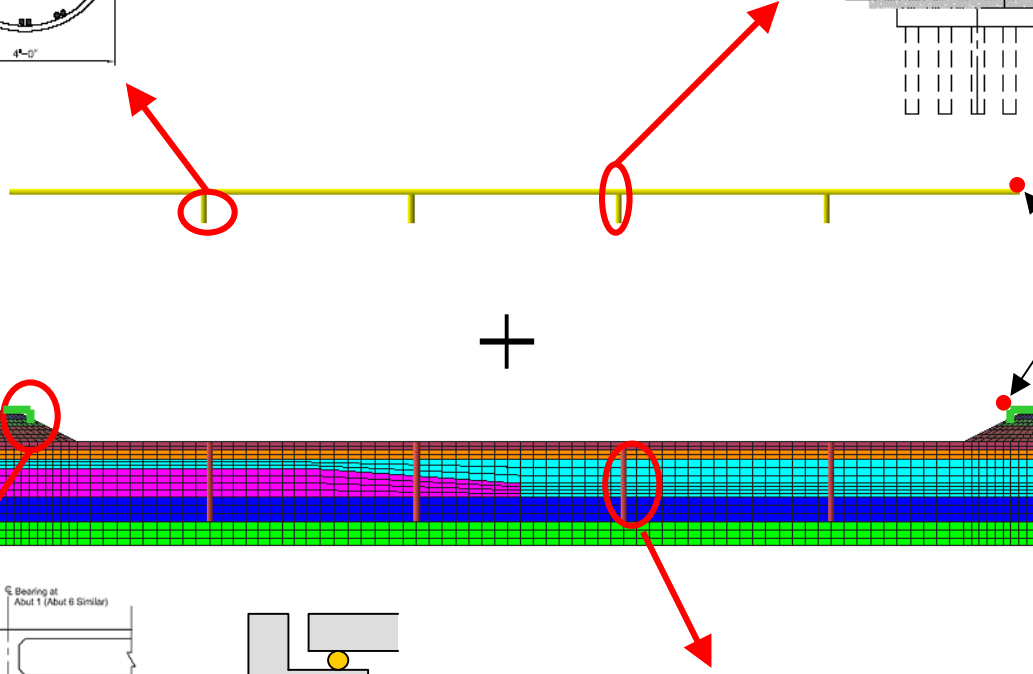
Geotechnical Modeling - Example

reinforced conrete column
(column A – 4 ft)



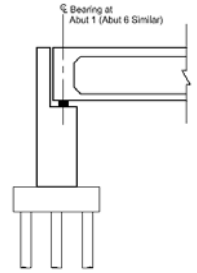
prestressed
reinforced concrete
bridge

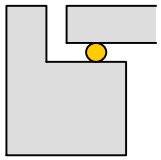




spring
connection

abutment



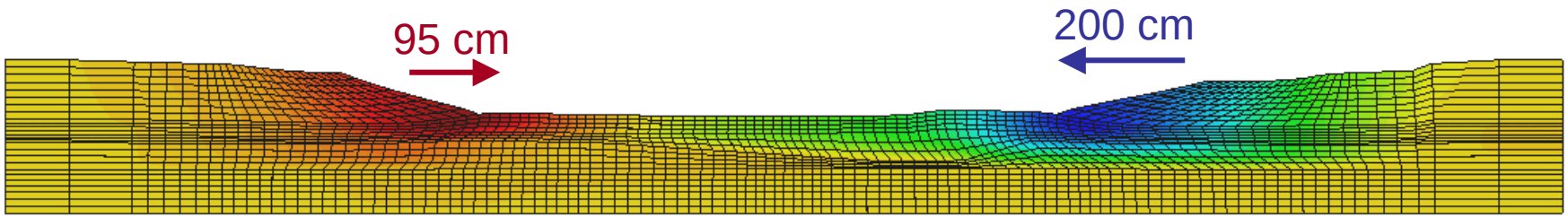


simplified abutment
(roller or spring)

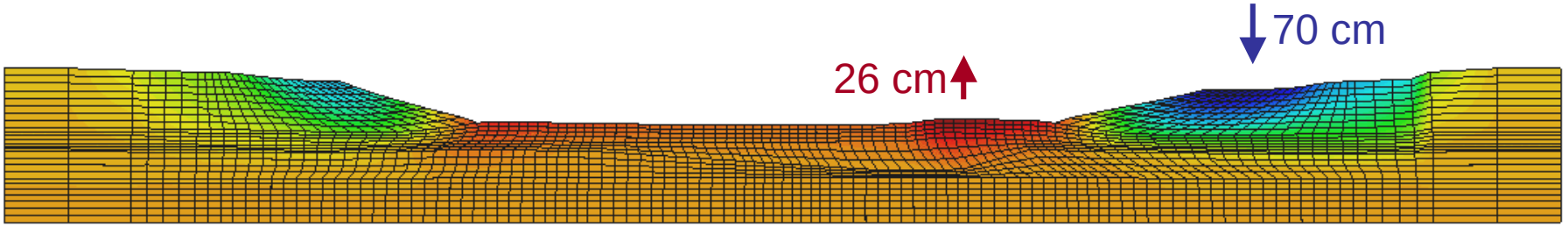
steel pipe pile
(8 ft diameter)

Geotechnical Modeling - Example

Horizontal displacements



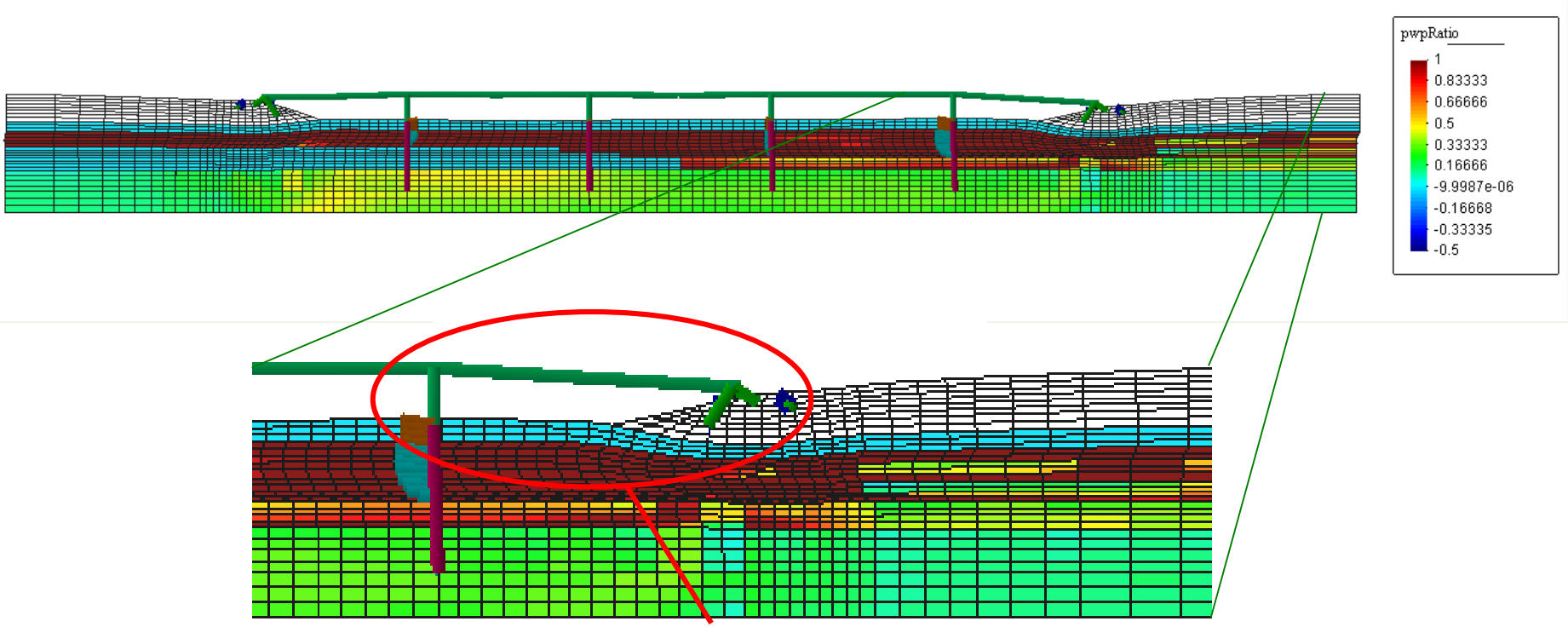
Vertical displacements



Geotechnical Modeling - Example

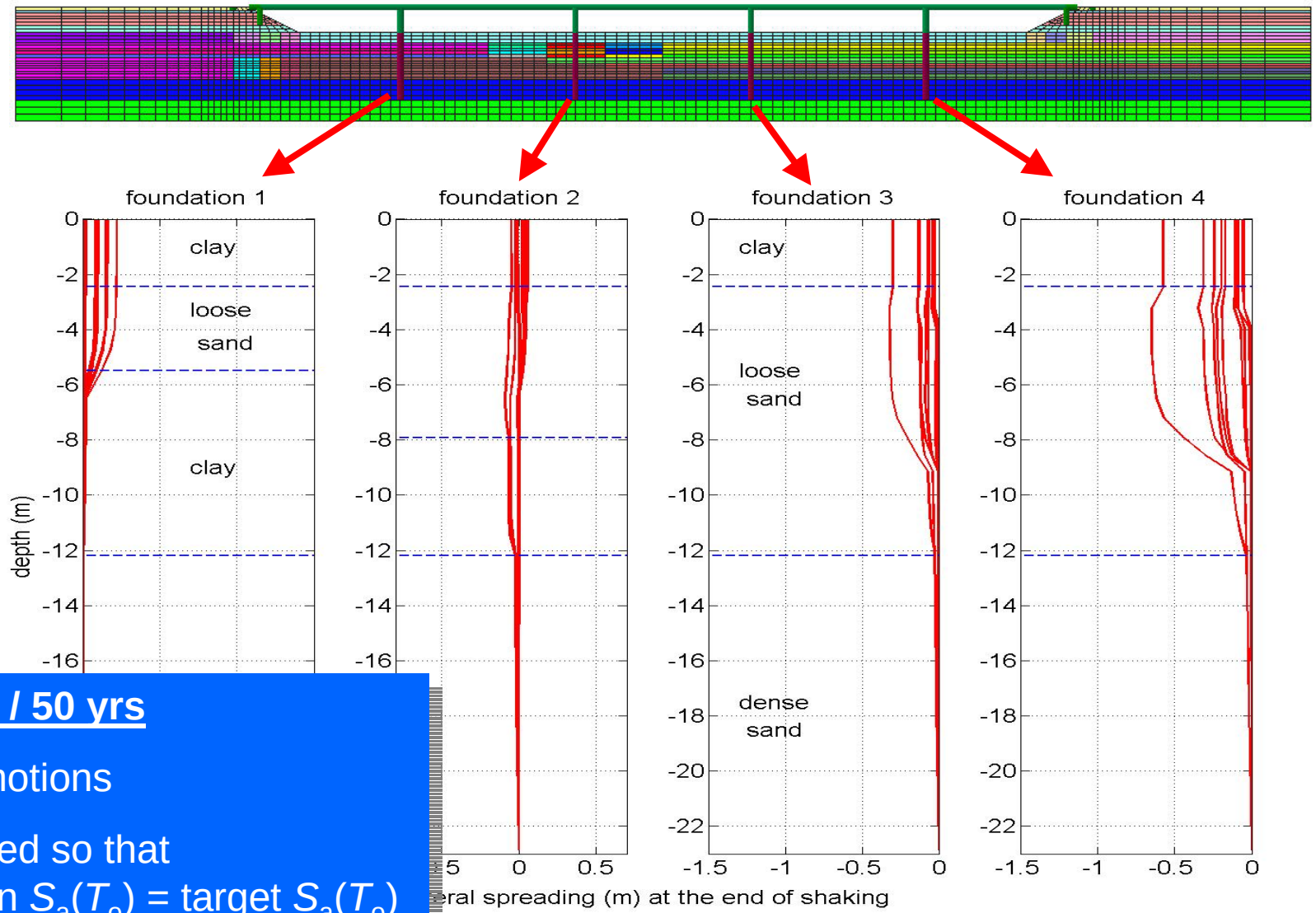
Ground failure

- Lateral spreading
- Settlement



Different form of loading on bridge

Geotechnical Modeling - Example

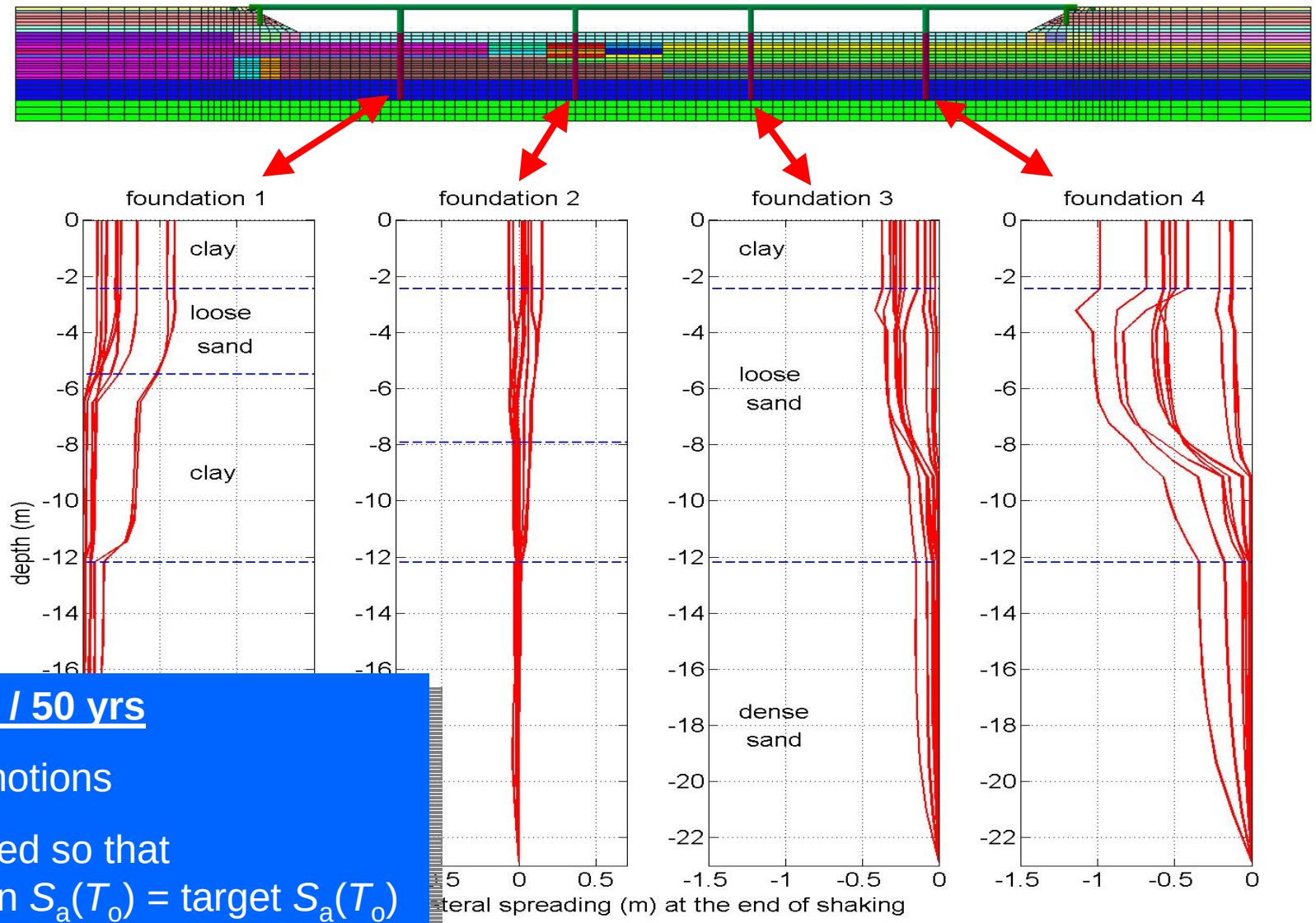


50% / 50 yrs

10 motions

Scaled so that
mean $S_a(T_o)$ = target $S_a(T_o)$

Geotechnical Modeling - Example



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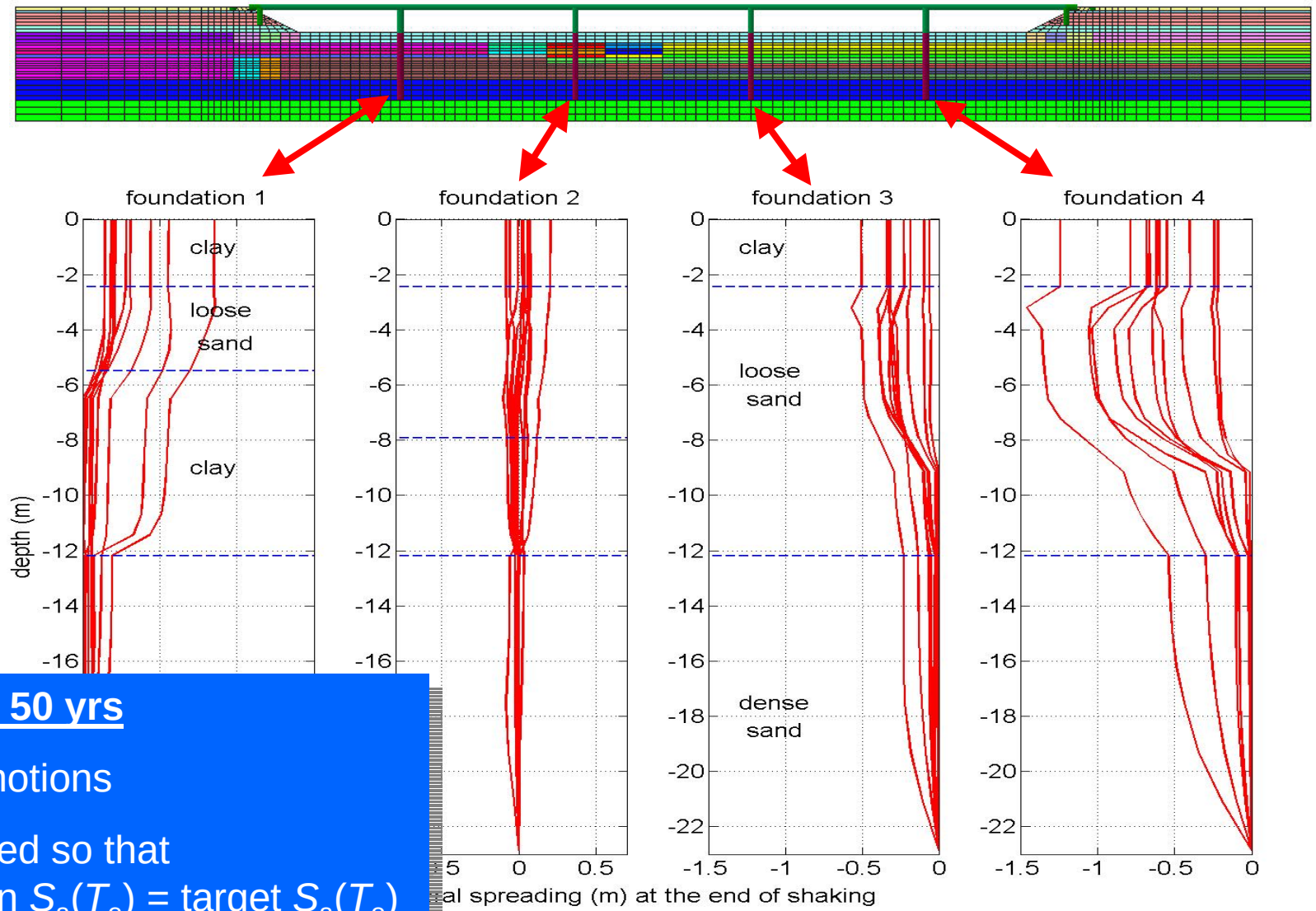


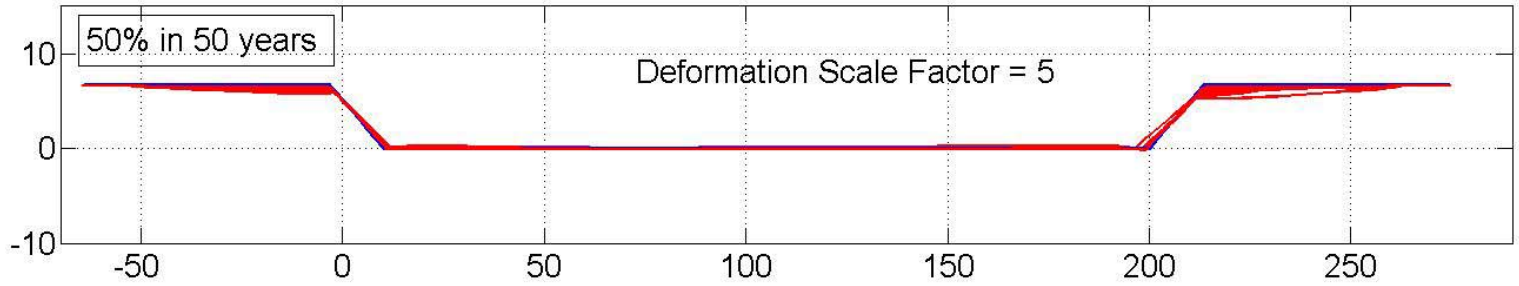
2% / 50 yrs

10 motions

Scaled so that
mean $S_a(T_o)$ = target $S_a(T_o)$

Geotechnical Modeling - Example

Ground surface settlement



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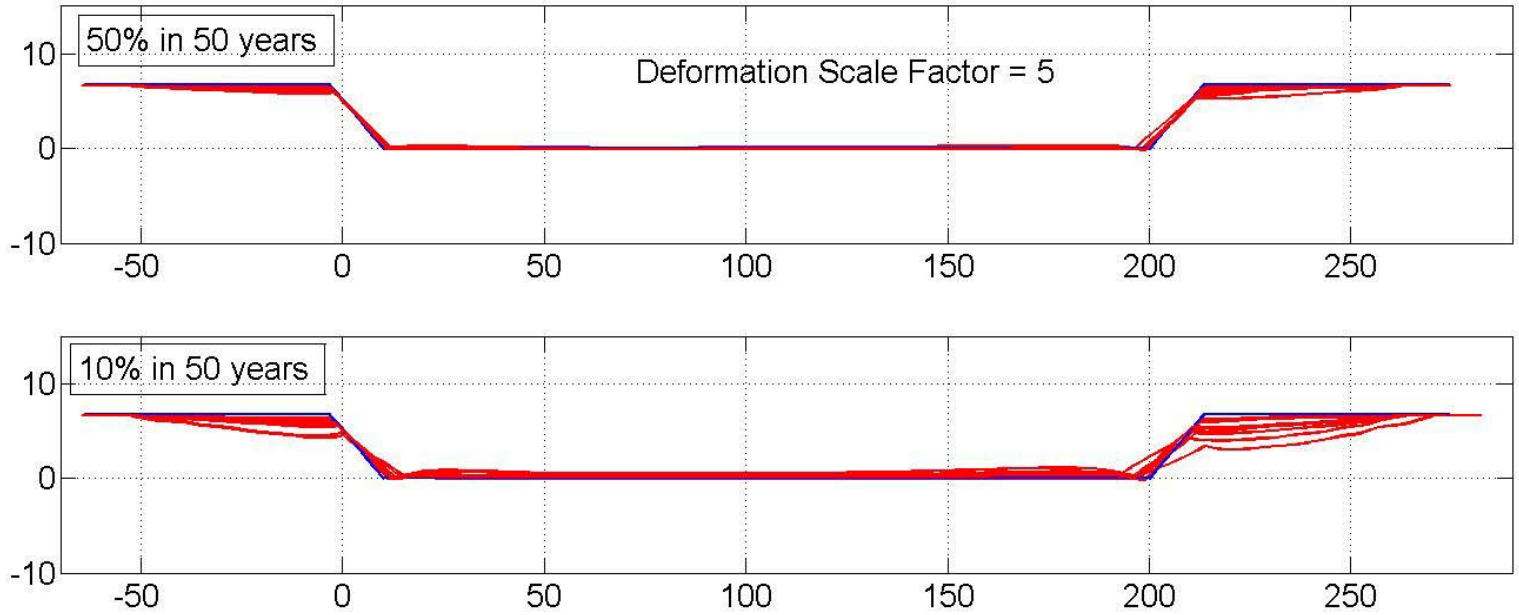

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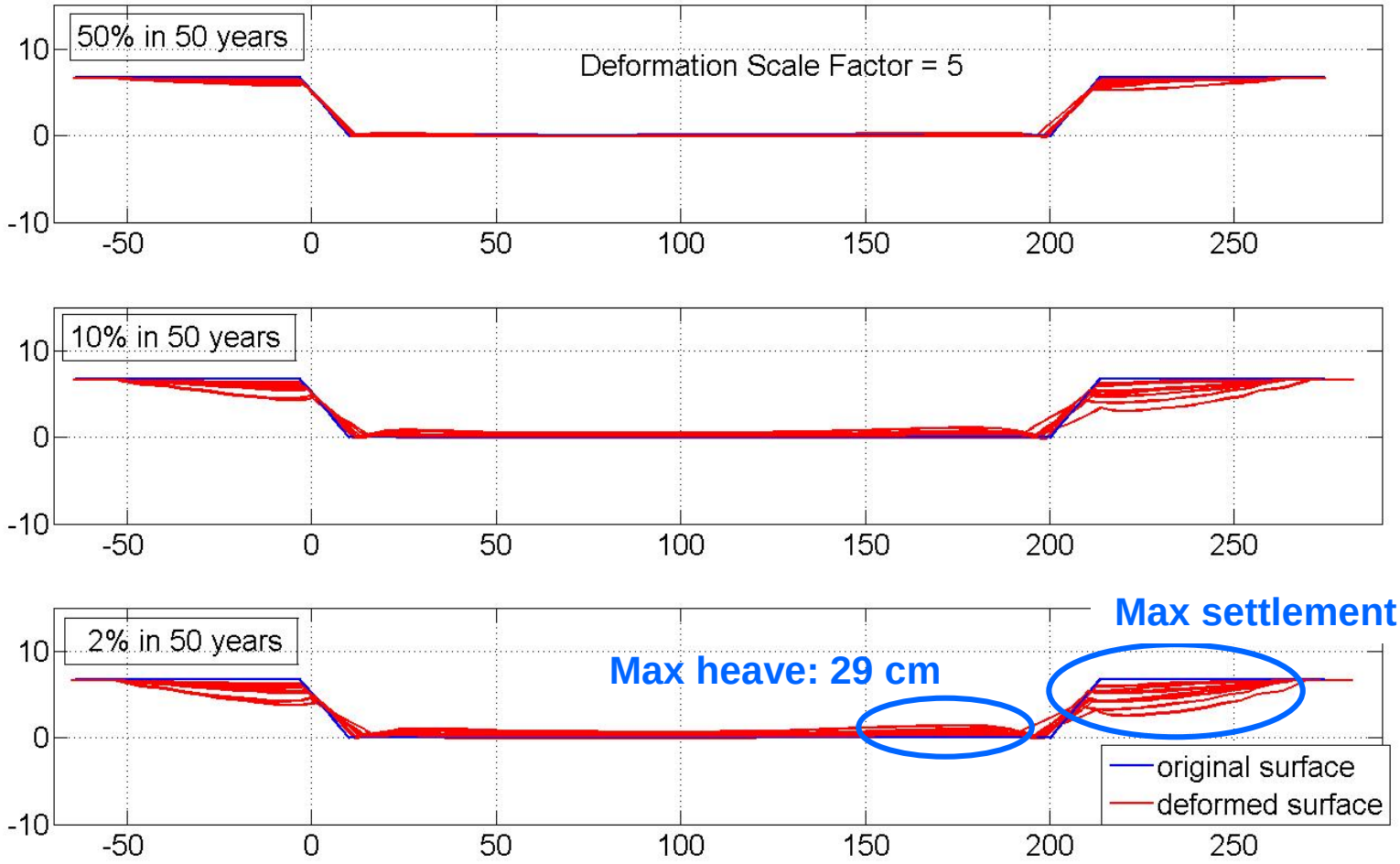

Geotechnical Modeling

Conclusions:

- Many complex geotechnical aspects to complete modeling of bridge-soil system
- OpenSees has capabilities for addressing nearly all of these in fairly rigorous fashion
- OpenSees is unique in level of rigor with which soil and structural response can be modeled in coupled manner
- OpenSees calculations are time-consuming for rigorous model
- Several approximations can be made w/r/t dimensions, geometry for soil model, foundation models
- Results of analyses provide insight into response, damage mechanisms