SOIL-PILE-STRUCTURE INTERACTION - Geotechnical

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SOIL-PILE-STRUCTURE INTERACTION - Geotechnical

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Presentation Outline

- Presentation Objectives
- Considerations of the soil-structure
- Framework of Development
- Soil-structure Modeling
- Validation of Model
- Application to the NMSZ
- Summary & Conclusions

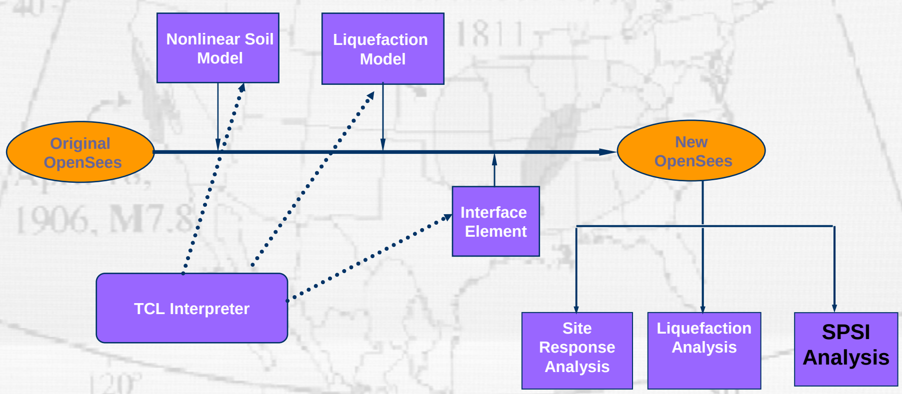
Objectives

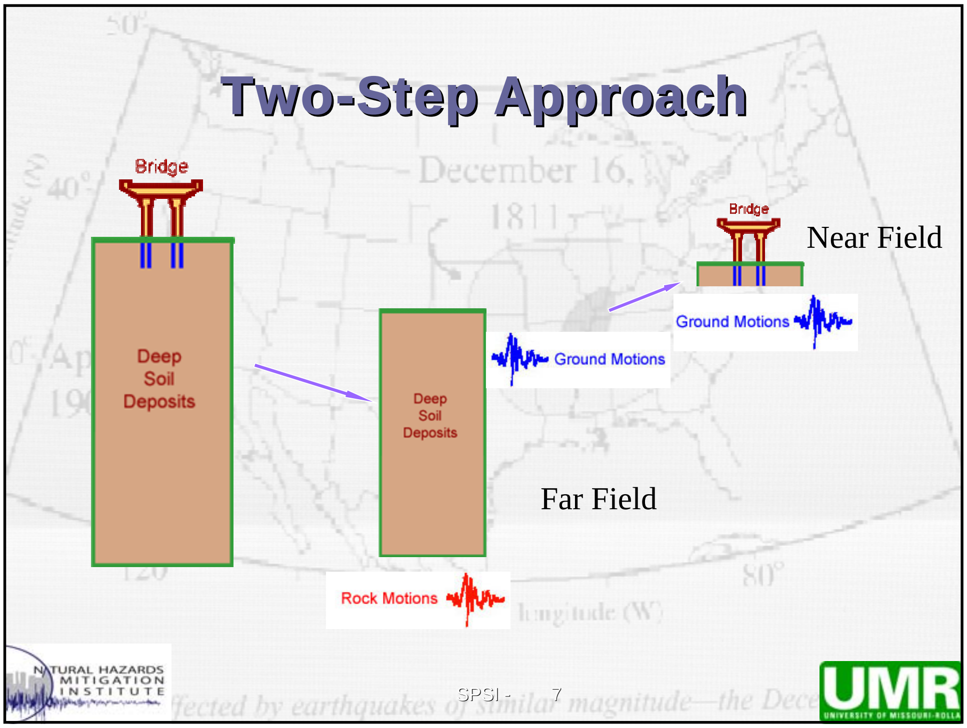
- Obtain ground motions at ground surface in time domain modeling
- Develop soil-pile interface elements and springs to model soil behavior.
- Examine the effect of liquefaction on foundations systems.

Development of Simulation System

- **Research Outline**
  1. Deep Ground Response Analysis
  2. Liquefaction Analysis in the NMSZ
  3. **SPSI Analysis in the NMSZ**
- OpenSees is used as a numerical simulation tool.

Work Chart of Programming




Two-Step Approach
Bridge
Deep
Soil
Deposits
Bridge
Near Field
Ground Motions
Ground Motions
Deep
Soil
Deposits
Far Field
Rock Motions
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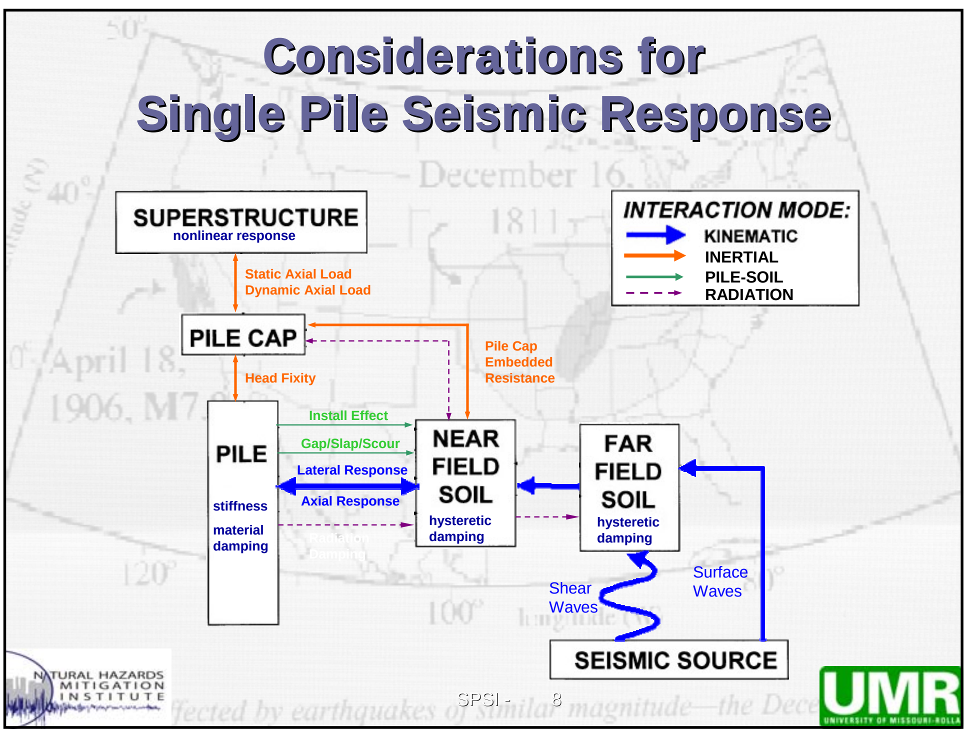
Considerations for
Single Pile Seismic Response
SUPERSTRUCTURE
nonlinear response
INTERACTION MODE:
KINEMATIC
INERTIAL
PILE-SOIL
RADIATION
Static Axial Load
Dynamic Axial Load
PILE CAP
Pile Cap
Embedded
Resistance
Head Fixity
Install Effect
Gap/Slap/Scour
Lateral Response
Axial Response
PILE
stiffness
material
damping
NEAR
FIELD
SOIL
hysteretic
damping
FAR
FIELD
SOIL
hysteretic
damping
Shear
Waves
Surface
Waves
SEISMIC SOURCE
NATURAL HAZARDS
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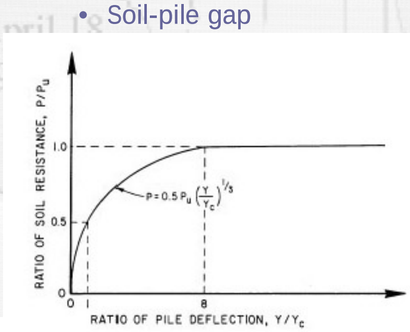
Methods for SPSI Analysis

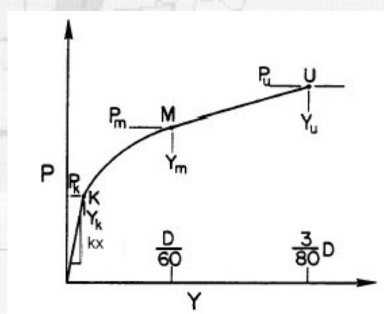
- Existing methods for SPSI analysis:
  - Simplified substructure methods that uncouples the superstructure and foundation portions of the analysis.
  - Dynamic beam on Winkler foundation (dynamic p-y curve) method.
  - 2D and 3D modeling of the pile and soil continuum using finite element or finite difference method.
- Dynamic p-y curve methods are considerably less complex than finite element or finite difference modeling and provide several potential advantages over the simplified substructure method.

What is p-y curve?

- p – lateral soil resistance
- y – lateral pile deflection
- Stiffness derived from field test and normally stiffer with depth
- Nonlinear p-y spring components
  - Elastic component
  - Plastic component
  - Soil-pile gap



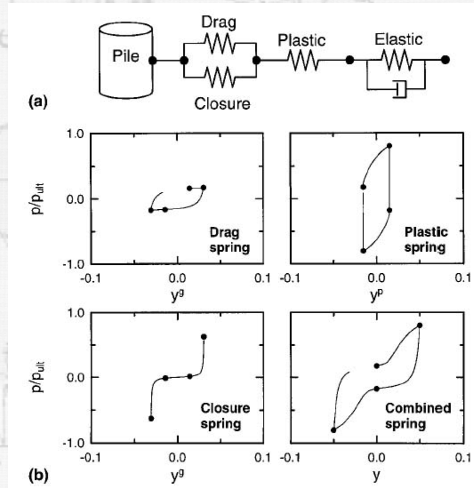
Clay (Matlock,1970)



Sand (Reese et al.,1984)

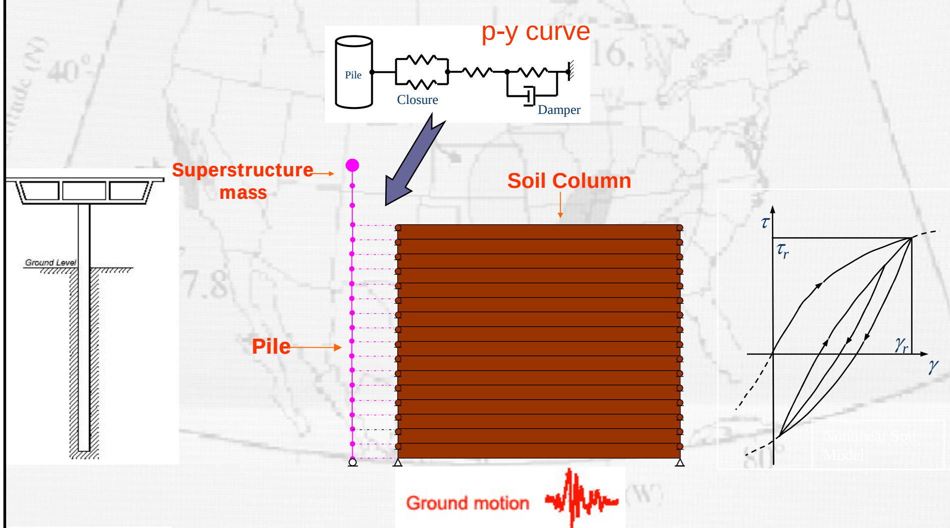
Dynamic nonlinear *p-y* Curves

- Boulanger et al. (1999) presented a nonlinear *p-y* element.
- The nonlinear ***p-y*** behavior is conceptualized as consisting of elastic, plastic, and gap components in series.



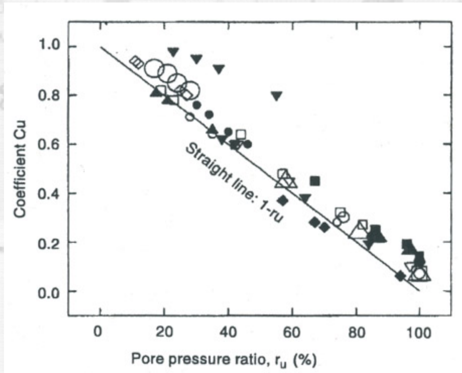
Characteristics of Dynamic Nonlinear *p-y* Element

Coupled SPSI Approach



Liquefaction Consideration

- Softening of p-y relationship with increasing pore water pressure was found in lots of centrifuge tests. A degradation parameter C_u is determined and applied to the ultimate soil resistance P_u.



Dobry and Liu (1995)

Liquefaction Consideration

- When considering loading rate, Wilson (1998) found an appropriate multiplier for peak loads during an earthquake in a pseudo-static analysis in liquefying sand would be 0.25-0.35 for Dr = 55%, and 0.10 for Dr = 35%.

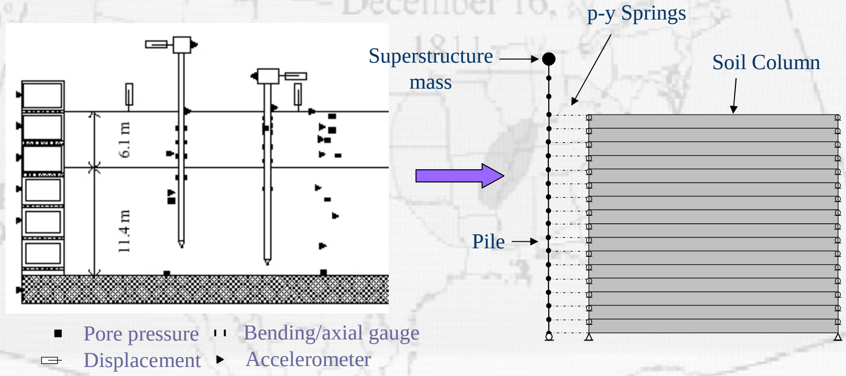
Loose sand

$$C_u = 1 - 0.9 r_u$$

Medium dense sand

$$Cu = 1 - 0.65 r_u$$

Model Calibration



Centrifuge Tests (UC, Davis)

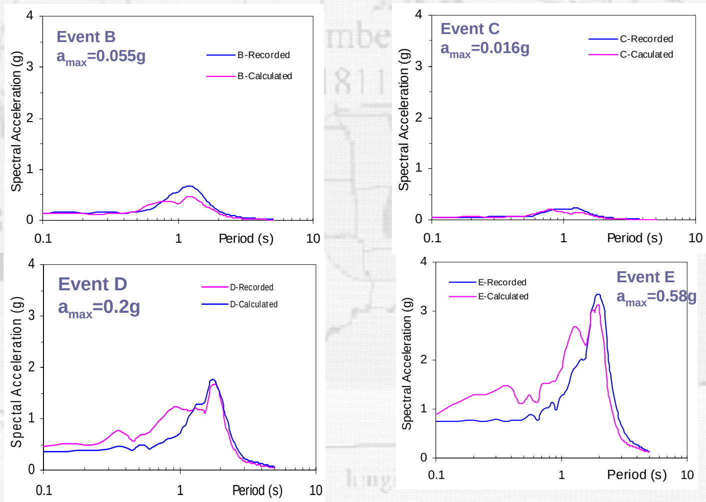
UMR Model

Earthquake Events

Earthquake Events for Centrifuge Tests

Event	Motion	a_{max} base input (g)
A	Kobe	0.055
B	Kobe	0.055
C	Kobe	0.016
D	Kobe	0.20
E	Kobe	0.58

Spectra Comparison - Superstructure



Comparison of Spectral Acceleration at Superstructure for Events B-E (5% damping)

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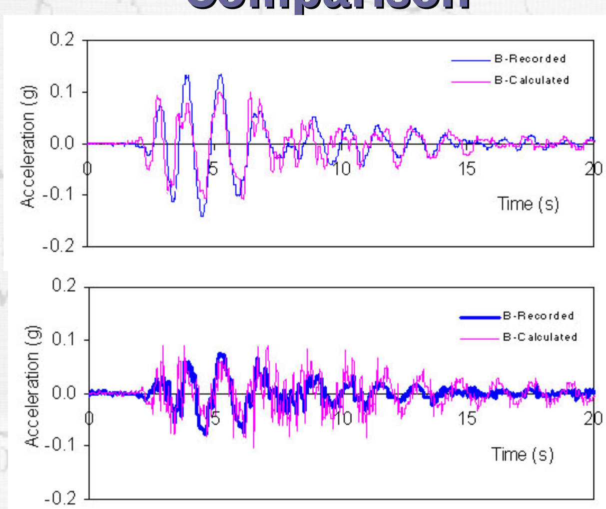
Acceleration Time Histories Comparison



Comparison of Time Histories during Event B (a) Superstructure (b) Pile Head

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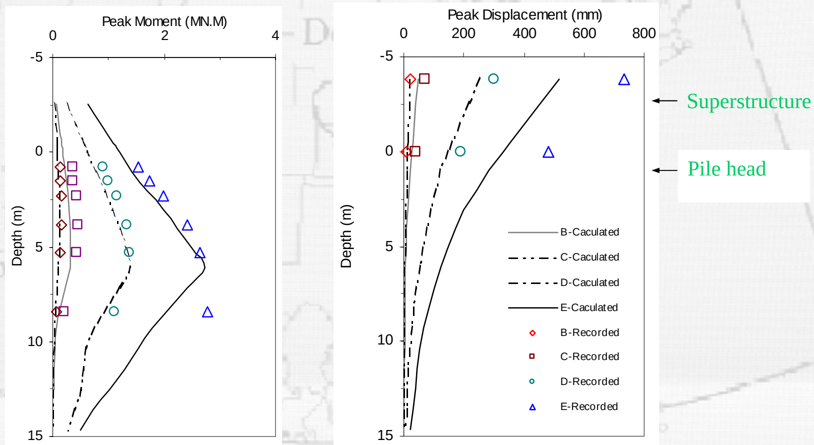
Displacement and Moment Comparison



Comparison of Calculated and Recorded Peak Relative Displacements during Events B-E

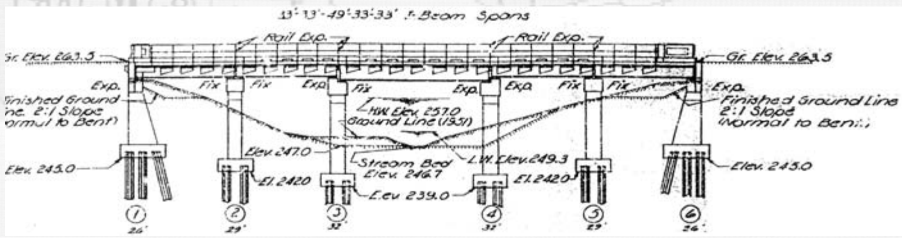
Application in the NMSZ

- Presented SPSI analysis method is applied to a highway bridge (L472 site).
- Synthetic ground motions were used and propagated up to the bottom of the pile foundations using the site response analysis.

Bridge Type

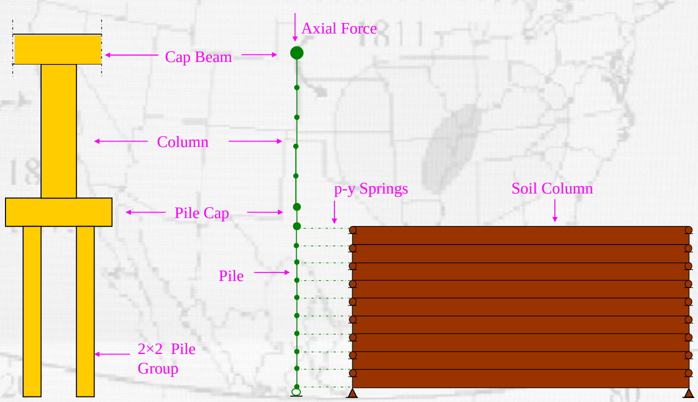
Elevation of Bridge L-472

This bridge was originally built as a multi-span simply supported steel girder bridge in the early 1950s, then enlarged and revised in 1971, and finally revised with deck repairs in 1984.



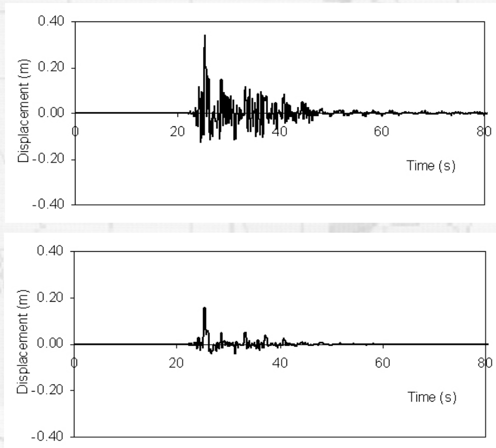
Elevation of Bridge L-472

Application to L472



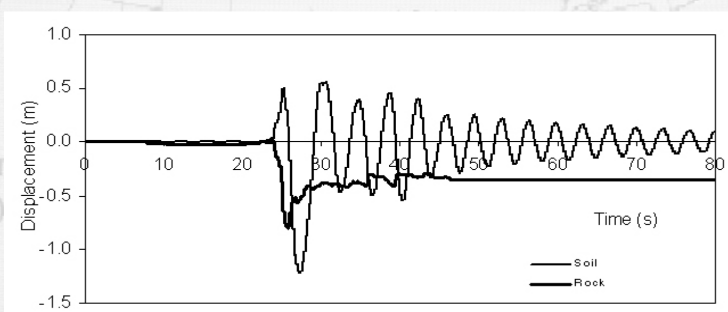
Finite Element Model for the Coupled SPSI Analysis

Results of Analysis



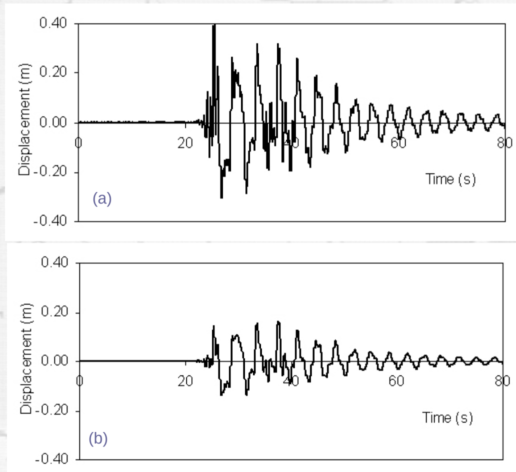
Displacement Histories for Analysis without Liquefaction Consideration in FN Direction (a) Beam Cap (b) Pile Cap

Results of Analysis



Displacement Histories at Rock Base and the Bottom of Pile Foundation for FN Direction

Results of Analysis



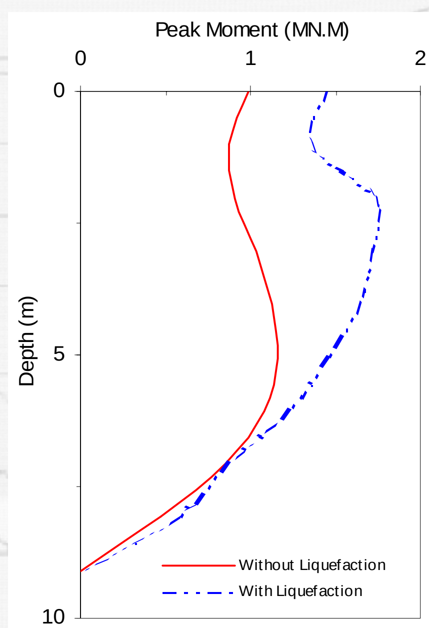
← Cap Beam

← Pile Cap

Displacement Histories for Analysis with Liquefaction Consideration in FN Direction (a) Beam Cap (b) Pile Cap

Results of Analysis

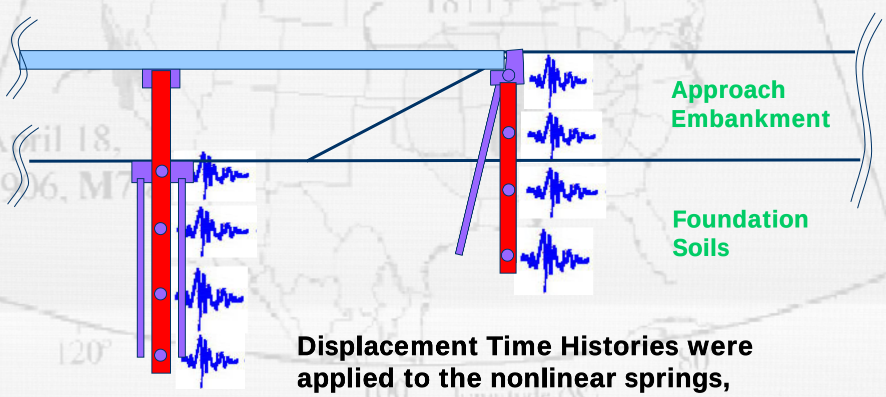
Peak Moment Comparison in FN Direction



Other Considerations

- Dynamic Group Pile Effects
  - from scaled testing (Lok (1999)
- Effect of liquefaction was only considered in the saturated foundation soils. However, the impact on the embankment was considered.
- These different geotechnical components were assembled around the structure to simulate dynamic behavior.

Modeling Geotechnical Conditions to the Superstructure



Displacement Time Histories were applied to the nonlinear springs, which include liquefaction effects

Summary & Conclusions

Summary of Findings

- A coupled SPSI analysis method was developed and verified with an instrumented centrifuge test results.
- This method has been applied to evaluate the seismic response of the highway bridges in the NMSZ.
- Dynamic nonlinear p-y method was adopted to simulate the interaction between pile and soil.

Summary of Findings

- A degradation multiplier at the pile soil-interface is introduced to the p-y curve to consider softening due to pore water pressure generation which induces liquefaction.
- The results indicate that the degradation of soil spring due to the pore water pressure greatly influence the foundation and superstructure response. Larger displacements and moments were found due to the softening of the soil springs.

Summary of Findings

- Near field energy pulse could be transmitted to the piles and other bridge components after propagating through the inelastic behavior of pile-soil interaction.
- However, near-field properties in the superstructure are not as significant as when the degradation of soil springs due to the pore water pressure is considered.

Final Comments

- The nonlinear effects near the surface tend to decrease the acceleration response spectra. However, there is a trade-off for these reduced spectra, that is, the larger deformations (straining) that the soil-structure undergoes to dissipate that energy. In saturated deposits these large nonlinear deformations may be a result of liquefaction which dramatically reduces the soil's ability to bear load.

Thank You!

Questions/Comments

The End