Geotechnical Design and Retrofit of Bridge Foundations

A Look Into the Future

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Technical Issues

- Ground Motion Characterization
- Geotechnical Performance Analyses
- Geotechnical Construction

Time Frames

- Near Term: 10 – 20 Years
- Long Term: >> 20 Years
Ground Motions

Current Practice

- Frequency Domain Characterization
  - Supplemented with Scenario Events
- Decoupled Seismic Hazard and Site Response
  - NEHRP Site Factors
  - 1-D Equivalent Liner Site Response
Ground Motions

Issues

- Decoupling Distorts the Uniform Hazard Spectra
- Soil is Non-Linear
- NEHRP Site Factors Oversimplify
- We Know 2-D and 3-D Effects can be Important
# Deaggregated Uniform Hazard

Deaggregated Seismic Hazard PE = 2% in 50 years pga  
Bakersfield CA 35.373 deg N 119.018 deg W PGA=0.42440 g  

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Deaggregated Seismic Hazard PE = 2% in 50 years lhz  
Bakersfield CA 35.373 deg N 119.018 deg W SA= 0.38360 g  

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NEHRP Site Factors

Equivalent Profiles?

40 ft
Soft Soil
$V_s = 600 \text{ fps}$

60 ft
Weak Rock
$V_s = 3000 \text{ fps}$

100 ft
Stiff Soil
$V_s = 2000 \text{ fps}$
NEHRP Site Factors

Equivalent Profiles?

100ft

Soil
\( V_s = 1500 \text{ fps} \)

Rock
\( V_s = 5000 \text{ fps} \)

\( > 1000 \text{ ft} \)

Soil
\( V_s = 1500 \text{ fps} \)
Charleston, SC Response Spectra

SCDOT SEE D Spectrum

Unconservative here

Over-conservative here

Site-specific time history analysis

PSA, g

Period, seconds/cycle

Courtesy J. Martin, Virginia Tech

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Design and Retrofit of Bridge Foundations
A Look Into the Future

Ground Motions
Future Developments:
Near Term
• Integrated Hazard and 1-D Site Response

Site Response Model
Ground Motions

Future Developments: Near Term

- Development of 2-D Response Factors
  - Bray: 1.3 Factor on PGA for Topographic Amplification
  - Basin Edge Factors
Design and Retrofit of Bridge Foundations
A Look Into the Future

Ground Motions

Future Developments: Near Term

- Non-Linear Time Domain Analysis
Ground Motions

Future Developments: Long Term

- Fully Integrated 2-D and 3-D Hazard and Site Response Models
- Enhanced Site Characterization
  - Necessary for 3-D Modeling
  - Use Geophysics to See Into the Earth and Interpolate Borings
Seeing Into the Ground

2-D Slice 2 ft below Ground Surface from GPR
Design and Retrofit of Bridge Foundations
A Look Into the Future

Ground Motions

Future Developments: Long Term

- Fully Integrated 2-D and 3-D Hazard and Site Response Models (Cont.)
  - Output Suites of Time Histories and Associated Weighting Factors
    - At Surface or Designated Depth
Integrated Probabilistic Seismic Hazard Analysis with Non-linear Site Effects (PSHA-NL)

1D Nonlinear site response analysis using DEEPSOIL

Probabilistic seismic hazard analysis with ground motion generation

Courtesy Youssef Hashash, U. Illinois
Design and Retrofit of Bridge Foundations
A Look Into the Future

Geotech Performance Analyses

Current Practice

- Deterministic Performance Analysis
- Decoupled Performance Analysis
- Adjust Structure to Accommodate Site Response
- Mechanical Ground Improvement
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A Look Into the Future

Geotech Performance Analyses

Issues

• Deterministic Performance Analysis Inconsistent with Probabilistic Response
  • Use 3 to 7 Time Histories
  • Take Maximum or Average Response

• Decoupled Performance Analysis Can be Extremely Conservative
  • Not a Real Measure of Seismic Performance, e.g. Seismic Deformation of Slopes
Newmark Decoupled Displacement Analysis for Slope Deformation

Franklin & Chang 1977 procedure
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A Look Into the Future

Geotech Performance Analyses
Issues

- Adjusting Structure to Accommodate Site Place Entire Burden on Structure
- Mechanical Ground Improvement can be Disruptive, Damaging, Expensive
  - Settlements Associated with Densification
  - Cost Associated with Grouting
Geotech Performance Analyses

Future Developments: Near Term

- LRFD – Semi-Probabilistic
- Stochastic Performance Models
Geotech Performance Analyses

Future Developments: Near Term

- Fully-Coupled Time-Domain Performance Analyses
  - Slip Elements
  - Strain Localization
Strain Localization
Geotech Performance Analyses

Future Developments: Near Term

- Improved and New Mechanical Stabilization Methods
  - Electro-Osmosis in Soft Soils
Geotech Performance Analyses

Future Developments: Long Term

- Fully Integrated Hazard – Site Response – Performance Models
Integrated Probabilistic Seismic Hazard Analysis with Non-linear Site Effects (PSHA-NL)

Probabilistic seismic hazard analysis with ground motion generation

1D Nonlinear site response analysis using DEEPSOIL

Structure Performance Model

Site

Surficial layers

1D Nonlinear site response analysis using DEEPSOIL

Courtesy Youssef Hashash, U. Illinois
Geotech Performance Analyses

Future Developments: Long Term

- Modify the Ground Response to Accommodate the Structure
  - Stiffness
  - Wave Guides and Wave Traps
Abrahamson & Silva (1997) - Rock/shallow soil - Strike Slip - M: 7 - R: 10 km

- Median + SD
- Median
- Median - SD

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Geotech Performance Analyses
Future Developments: Long Term

- Bio-Improvement of Soils
  - Induced Cementation in Granular Soils
    - Remediate Liquefaction
    - “Grow” Foundation in Place
  - Mineral Transformation in Clays
Microorganisms & Geological Processes

Lithification

Diagenesis
Bio-Modification of Soils

Laboratory-Induced Carbonate Precipitation on Sand
Remediation of Liquefaction
Summary – What Does the Future Hold

• Near Term
  • Incremental Improvements
  • Begin Transition to Fully Integrated Analyses

• Long Term
  • Computation Intensive Integrated Analysis
  • Bio-Geotech