GROUND MOTIONS AND SEISMIC STABILITY OF EMBANKMENT DAMS

FAIZ I. MAKDISI
AMEC, E&I, INC.
OAKLAND, CA
BRIEF COMMENTS AND QUESTIONS

- Number of time histories (matched and or scaled)
- Use of Uniform hazard spectra vs. conditional mean spectra
- Use of multiple analyses in estimates of deformation
- Example of time domain equivalent linear analysis with loading history-dependent modulus and damping
Matched Vs. Scaled Time Histories

Compacted clay embankment

H = 150 feet
Vs= 1,000 fps
Unit weight = 120 pcf

Next Generation Attenuation Relationships Workshop
2014 Annual Meeting and Conference, San Francisco, California
<table>
<thead>
<tr>
<th>No</th>
<th>Event</th>
<th>Station</th>
<th>NGA #</th>
<th>Year</th>
<th>M</th>
<th>Mechanism</th>
<th>Rrup (km)</th>
<th>Vs,30 (m/s)</th>
<th>FileName</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kobe, Japan</td>
<td>Nishi-Akashi</td>
<td>1111</td>
<td>1995</td>
<td>6.90</td>
<td>SS</td>
<td>7.1</td>
<td>609</td>
<td>NIS_FN</td>
</tr>
<tr>
<td>2</td>
<td>Loma Prieta</td>
<td>UCSC Lick Observatory</td>
<td>810</td>
<td>1989</td>
<td>6.93</td>
<td>RV-OBL</td>
<td>18.4</td>
<td>714</td>
<td>LOB000</td>
</tr>
<tr>
<td>3</td>
<td>Loma Prieta</td>
<td>LGPC</td>
<td>779</td>
<td>1989</td>
<td>6.93</td>
<td>RV-OBL</td>
<td>3.9</td>
<td>478</td>
<td>LGP_FN-</td>
</tr>
<tr>
<td>4</td>
<td>Northridge-01</td>
<td>LA - UCLA Grounds</td>
<td>1006</td>
<td>1994</td>
<td>6.69</td>
<td>Reverse</td>
<td>22.5</td>
<td>398.4</td>
<td>UCL_FN</td>
</tr>
<tr>
<td>5</td>
<td>Loma Prieta</td>
<td>Anderson Dam (Downstream)</td>
<td>739</td>
<td>1989</td>
<td>6.93</td>
<td>Reverse-Oblique</td>
<td>20.3</td>
<td>488.8</td>
<td>AND_FN</td>
</tr>
<tr>
<td>6</td>
<td>Friuli- Italy-01</td>
<td>Tolmezzo</td>
<td>125</td>
<td>1976</td>
<td>6.5</td>
<td>Reverse</td>
<td>15.8</td>
<td>424.8</td>
<td>A-TMZ_FN</td>
</tr>
<tr>
<td>7</td>
<td>Northridge-01</td>
<td>LA - Wadsworth VA Hospital South</td>
<td>1010</td>
<td>1994</td>
<td>6.69</td>
<td>Reverse</td>
<td>23.6</td>
<td>413.8</td>
<td>5082_FN</td>
</tr>
<tr>
<td>8</td>
<td>Northridge-01</td>
<td>Glendale - Las Palmas</td>
<td>974</td>
<td>1994</td>
<td>6.69</td>
<td>Reverse</td>
<td>22.2</td>
<td>446</td>
<td>GLP_FN</td>
</tr>
<tr>
<td>9</td>
<td>San Fernando</td>
<td>Lake Hughes #12</td>
<td>71</td>
<td>1971</td>
<td>6.61</td>
<td>Reverse</td>
<td>19.3</td>
<td>602.1</td>
<td>L12_FN</td>
</tr>
</tbody>
</table>
MATCHED VS. SCALED TIME HISTORIES

3 matched time histories

9 scaled time histories to target PGA

Next Generation Attenuation Relationships Workshop
2014 Annual Meeting and Conference, San Francisco, California

MATCHED VS. SCALED TIME HISTORIES

3 matched time histories

9 scaled time histories to target PGA

Next Generation Attenuation Relationships Workshop
2014 Annual Meeting and Conference, San Francisco, California
MATCHED VS. SCALED TIME HISTORIES

Deformation, $u \text{ (m)}$

$K_y/K_{\text{max}}$

Next Generation Attenuation Relationships Workshop
2014 Annual Meeting and Conference, San Francisco, California
FOR EMBANKMENT DAMS:

RESPONSE IS A FUNCTION OF THE FIRST THREE MODES OF VIBRATION:

- T₁ = 2.6 H/Vs   \( \phi_1 = 1.6 \)
- T₂ = 1.13 H/Vs  \( \phi_2 = 1.06 \)
- T₃ = 0.72 H/Vs  \( \phi_3 = 0.86 \)
RESPONSE IN NON-LINEAR (STRAIN-DEPENDANT)
CRANE VALLEY DAM

HAZARD DEAGGREGATION

Next Generation Attenuation Relationships Workshop
2014 Annual Meeting and Conference, San Francisco, California
DEFORMATION ESTIMATES USING NON-LINEAR ANALYSES

EXAMPLE STUDY
Qaraoun Dam Maximum (Center) Section
FLAC Grid and Material Zones

- User-defined Groups
  - Bedrock
  - Concrete_DrainGal
  - Rockfill_Dumped
  - Rockfill_Stratified

Liner element modeling concrete facing on top of Rockfill_Stratified layer

Concrete Inspection/Drainage Gallery
INPUT EARTHQUAKE GROUND MOTION 2,475-YR EVENT (TABAS RECORD)

Horizontal

Vertical

Next Generation Attenuation Relationships Workshop
2014 Annual Meeting and Conference, San Francisco, California
Computed deformed mesh and contours of maximum shear strain increment (SSI) at end of earthquake, 2,475-yr event (Tabas record)

Max. shear strain increment
- 0.00E+00
- 2.50E-03
- 5.00E-03
- 7.50E-03
- 1.00E-02
- 1.25E-02
- 1.50E-02
- 1.75E-02
- 2.00E-02
- 2.25E-02

Contour interval = 2.50E-03
Extrap. by averaging

Exaggerated grid distortion
Magnification = 5.000E+00
Max Disp = 6.664E-01
Crest Settlement vs Earthquake Severity Index (ESI)

ESI = PGA \cdot (M - 4.5)^3

Next Generation Attenuation Relationships Workshop
2014 Annual Meeting and Conference, San Francisco, California
Performance of Ishibuchi Dam (Japan) Concrete-faced Rockfill Dam

- 2008 $M_w$ 6.9 Miyage earthquake at 11 km
- 53-meter-high concrete-faced, dumped rockfill dam built in 1953, a process similar to Qaraoun dam
- Peak acceleration at the base = 0.6-0.7g
- Recorded crest acceleration = 1.5g
- Measured settlement at crest at maximum section of 0.6m
- Settlement caused uneven pavement surface and cracking at crest, however, face slab was reportedly undamaged
GEOMETRY OF QARAOUN DAM VS. ISHIBUCHI DAM
## Multiple FLAC Analyses

**MOHR-COULOMB, URS-PP, UBCSAND**

<table>
<thead>
<tr>
<th>Model</th>
<th>Crest Horizontal Displacement (ft)</th>
<th>Crest Vertical Displacement (ft)</th>
<th>Max Vector Displacement (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Existing Dam</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLAC-MC</td>
<td>11</td>
<td>12</td>
<td>22</td>
</tr>
<tr>
<td>URS-PP</td>
<td>2.2</td>
<td>5.4</td>
<td>7.9</td>
</tr>
<tr>
<td>UBCSAND</td>
<td>1.7</td>
<td>3.1</td>
<td>4.9</td>
</tr>
<tr>
<td><strong>Modified Dam</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLAC-MC</td>
<td>1.2</td>
<td>1.6</td>
<td>4.0</td>
</tr>
<tr>
<td>URS-PP</td>
<td>0.1</td>
<td>2.2</td>
<td>3.5</td>
</tr>
<tr>
<td>UBCSAND</td>
<td>1.0</td>
<td>2.1</td>
<td>3.6</td>
</tr>
</tbody>
</table>
MULTIPLE DEFORMATION ANALYSES

- Use more than one analysis procedure and compare results with case histories
- Two useful nonlinear models that are based on proper mathematical formulation and appropriate calibration and documentation of model parameters:
  - Wang’s Hypo-plasticity model
  - Boulanger and Ziotopoulou PM4Sand Model
HISTORY-DEPENDENT MODULUS AND DAMPING RESPONSE

Wang and Ma (2013)
HISTORY-DEPENDENT MODULUS AND DAMPING RESPONSE

Next Generation Attenuation Relationships Workshop
2014 Annual Meeting and Conference, San Francisco, California
HISTORY-DEPENDENT MODULUS AND DAMPING RESPONSE

Next Generation Attenuation Relationships Workshop
2014 Annual Meeting and Conference, San Francisco, California
HISTORY-DEPENDENT MODULUS AND DAMPING RESPONSE

Next Generation Attenuation Relationships Workshop
2014 Annual Meeting and Conference, San Francisco, California