Comparison of Forced Vibration Testing Results to a Soil Structure Interaction Model

Dr. Robert Nigbor, Dr. Jonathan Stewart, Dr. Lisa Star, Omar Mauricio, and Kurt Kellogg

NEES@UCLA Mobile Laboratory

Soil Structure Interaction (SSI)

Impacts of SSI

- The rigid base approximation
  - Common construction practice treats both the foundation and soil as rigid, and does not account for SSI effects. This approximation is not always conservative for safety purposes. SSI affects the reaction of a structure in dynamic scenarios such as earthquakes and high wind conditions.
- Affected structural properties
  - Resonant frequency
  - Stiffness
  - Damping

Theoretical modeling of SSI

- Need for a model
  - Impractical to determine every structure’s properties experimentally
  - An accurate model can lead to safer construction practices and more efficient use of building materials
- Model features
  - Should be computationally simplistic
  - Should not require extensive testing of the structure or site
  - Should provide reasonable estimates of dynamic structural properties

Determine the structure’s dynamic response considering SSI effects

The Soil-Spring Model

- The flexible base correction
  - To account for foundation flexibility in both translational and rotational modes, the soil-foundation-structure system is modeled as a mass with a spring-dashpot couple as the base (see Fig. 1, right).
- Six modes of dynamic response
  - Three dimensions, two modes per dimension
  - Springs model translational modes
  - Dashpots model rotational modes

Figure 1: Simplified model of a structure with a fixed base (a) and flexible base (b).

Compare the soil-spring model prediction to experimental results

Forced Vibration Testing

- Mini-Me and the Garner Valley Site
  - Mini-Me (right) is a portable test structure used to determine SSI properties at several sites
  - Tests for this project were conducted at the Garner Valley Digital Array near Lake Hemet, CA.
- Instrumentation and Methodology
  - Triaxial accelerometers were implemented at each corner of the structure (Fig. 3a).
  - Frequency sweeps were performed from 4 to 54 Hz with a linear oscillating mass shaker (Fig. 3b).
  - Accelerations from structure and shaker were recorded using Quanterra Q330 Data Acquisition Systems (Fig. 3c).

Figure 2: The Mini-Me structure at Garner Valley

(a) (b) (c)

Figure 3 (left): Episensor ES-T triaxial accelerometer (a), Electro-seis M4000 shaker (b), and Q330 Data Acquisition System (c).

Results

<table>
<thead>
<tr>
<th>Condition</th>
<th>Direction</th>
<th>Model</th>
<th>f [Hz]</th>
<th>b [%]</th>
<th>k [MN/m]</th>
<th>Period Lengthening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Braced</td>
<td>X</td>
<td>Rigid</td>
<td>31</td>
<td>2%</td>
<td>823</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>13</td>
<td>6.92%</td>
<td>144</td>
<td>2.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Experiment</td>
<td>34.6</td>
<td>5.53%</td>
<td>181</td>
<td>2.32</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>Rigid</td>
<td>23</td>
<td>2%</td>
<td>453</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12.3</td>
<td>5.64%</td>
<td>127</td>
<td>1.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Experiment</td>
<td>10.8</td>
<td>5.89%</td>
<td>100</td>
<td>1.09</td>
</tr>
<tr>
<td>Unbraced</td>
<td>X</td>
<td>Rigid</td>
<td>11.8</td>
<td>2%</td>
<td>117</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9.34</td>
<td>2.98%</td>
<td>71.1</td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Experiment</td>
<td>9.86</td>
<td>3.09%</td>
<td>81.8</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>Rigid</td>
<td>13</td>
<td>2%</td>
<td>142</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9.72</td>
<td>3.26%</td>
<td>79.5</td>
<td>1.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Experiment</td>
<td>8.76</td>
<td>3.39%</td>
<td>64.5</td>
<td>1.48</td>
</tr>
</tbody>
</table>

Data Analysis

- Sweep selection
  - Corresponding 50 and 200 second segments of the hour-long data files were extracted. An example of one accelerometer’s response during a 50 sec. sweep can be seen on the right.
- Data Manipulation
  - Channels in the direction of shaking from the four accelerometers on each slab were averaged
  - Performed Fast Fourier Transform of averaged accelerations
  - Performed Fast Fourier Transform on acceleration data from uniaxial accelerometer attached to the shaker itself
  - Computed acceleration response factor by taking ratio of structural response to shaker input (Fig. 5)

Figure 4: Acceleration data from y-channel of top south accelerometer

Figure 5: Frequency domain acceleration response factor for a 50 second sweep

- Response peak analysis
  - Location of highest response factor peak represents resonant frequency
  - Half-power bandwidth takes the width of the peak at 1/2 of the peak amplitude
  - Ratio of bandwidth to resonant frequency is equal to twice the damping
  - Repeated for several sweeps in each direction to determine frequency, damping, stiffness, and period lengthening
  - Average results are compared to both rigid-base and soil spring models (left)

UCLA – UCR – Caltech – USC – UC Merced