SECTION 1: SOIL-STRUCTURE INTERACTION

1.1 Description and Treatment in 2003 NEHERP Recommended Provisions

Structures subjected to earthquake motion are generally analyzed using free field ground motions; that is, ground motions at the location of structure if structure were not there. This assumption, which simplifies the analysis, is although valid for structure on rock or stiff soils, might not be appropriate for a structure on soft soils. The fixed base assumption for the structure founded on rock or stiff soils imply that high stiffness of elastic soil media constrain the motion at the foundation of structure close to the free field motion. However, there is always some soil-structure interaction during earthquake shaking and the interaction is particularly predominant for structures founded on soft soils in which elastic media confining the foundation acts as flexible column and overall response of structure is modified by inertial and kinematic effects. SSI increases the fundamental period of structure which generally reduces base shear, lateral forces, and overturning moments but might increase the displacement demands.

Section 5.6 of FEMA 450 (Council, 2003) provides guidelines to account for the SSI in the analysis of structure using equivalent lateral force procedures and response spectrum procedure. Guidelines are not be used if the structure is modeled as flexible-base, rather than rigid base, in the analysis of structure. In both analysis procedures, it allows the reduction of base shear obtained without considering SSI. Reduced base shear is distributed over height using same procedure as used for fixed-base structure. Time period of structure is modified using a simplified model which takes into account the flexibility of soil-foundation system as shown in Figure 1.1. Hysteretic and radiation damping of foundation systems contributes to the total damping of structure and effective damping ratio is calculated as the sum of viscous damping of structure and damping due to SSI. Radiation and hysteretic damping is calculated using chart provided in the guidelines. The modified shears, overturning moments, and torsional effects are determined using same procedures as for structures without SSI but using reduced lateral forces.
Figure 1.1: Simplified oscillator model for analysis of inertial interaction under lateral excitation (Bozorgnia and Bertero, 2004)

1.2 Kinematic and Inertial Effects

Structure on soil exhibits two kinds of interaction effects known as kinematic and inertial effects. Kinematic interaction effects exist due to change in wave propagation media as a result of change in density and elasticity of the media. It changes the wave propagation velocity and leads to reflection and refraction of incoming seismic waves. Kinematic effects of SSI represent the change in response of structure when response is obtained using free-field motions and when the presence of structure is considered. It doesn’t depend on the mass of structure and is affected by the geometry and configuration of structure, the foundation embedment, the composition of incident free-field waves, and the angle of incidence of these waves (Villaverde, 2009). Kinematic interaction can be neglected for structures with no embedment excited by vertically propagating shear waves.

Inertial effects result from the combined dynamic behavior of structure, foundation, and supporting soil media. Soil media, owing to its elastic and inertial properties, increases the degrees of freedom of structure and makes it possible to dissipate energy of incoming seismic waves by the radiation of waves away from the structure and hysteretic deformation of supporting soil media. Inertial effect depends on the relative flexibility of supporting soil media to the structure, which implies that the effect is not significant for regular structure founded on
stiff soils or rock, but could be significant for stiff and massive structures like nuclear power plants founded on soft-soils.

1.3 Software Packages for SSI Analysis of Structures

Some of the software programs used for SSI analysis of structures are listed below:

1. SHAKE
2. SASSI
3. FLUSH
4. LSDYNA

There are two kinds of analysis methods that are used in contemporary software packages: 1) Direct method, and 2) Substructure method. Direct method models the soil and structure together and analyzes the combined system in a single step. Soil and structure are discretized in finite elements and nonlinear analysis can be performed. On the other hand, substructure method divides the analysis in three steps use the superposition to obtain the final response. It is solved in frequency domain analysis and assumes linear soil and structure behavior. Three steps used in substructuring method are:

i. Determination of foundation input motion.

ii. Dynamic analysis of soil media to obtain stiffness and damping characteristic of foundation-soil interaction.

iii. Analysis of structure supported on springs represented by step 2 and subjected to base excitation obtained in step 1.

SASSI and FLUSH use substructuring method using frequency domain analysis. Although less computationally expensive, these methods cannot perform nonlinear analysis and equivalent linearization with iterations is used. SHAKE is used for site response analysis to provide the input parameters required for SSI analysis in SASSI.
LSDYNA and other finite element packages (e.g., ABAQUS) use time domain methods and can perform nonlinear analysis. They uses the direct method in which the soil and structure is modeled and analyzed together. These software programs are computationally extensive when compared to frequency domain programs. Also, modeling a semi-infinite soil media is not possible and transmitting boundaries are used to reproduce the behavior. Moreover, there are identified issues with application of three-dimensional coupled ground motions to structures in direct methods.

1.4 SSI in Nuclear Power Plants

Nuclear power plant layout consists of a complex layout of heavy and massive structures at close distances. Nuclear Island is supported on a very stiff and heavy basemat and embedment of foundation might be significant. All these factors play important role in increased kinematic and inertial interactions. The rigidity and low height-width ratio dictates that rocking component of structural response might not be neglected. Although, neglecting SSI effects generally results in a conservative force demand, the aim with the analysis of nuclear power plants is to be accurate rather than conservative. Excessive mass and heavy size of nuclear power plant dictates that even though if it is built on relatively stiff soil, SSI effects might still be significant and needs to be considered for the analysis and design.
SECTION 2: SAP2000 MODEL OF HOSPITAL BUILDING

2.1 Reactive weights

<table>
<thead>
<tr>
<th>Floor</th>
<th>Reactive weight (Kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2828</td>
</tr>
<tr>
<td>2</td>
<td>2726</td>
</tr>
<tr>
<td>3</td>
<td>2798</td>
</tr>
<tr>
<td>4</td>
<td>2257</td>
</tr>
</tbody>
</table>

*Table 2.1*: Reactive weights at different floors of the structure

Total reactive weight: 10609 Kips

Total reactive mass: 329.5 Kips-s^2/ft

2.2 Modal Frequencies and Participating Mass

<table>
<thead>
<tr>
<th>Mode</th>
<th>Period</th>
<th>Cumulative % Mass (E-W)</th>
<th>Cumulative % Mass (N-S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.858</td>
<td>0</td>
<td>0.80431</td>
</tr>
<tr>
<td>2</td>
<td>1.764</td>
<td>0.83089</td>
<td>0.80431</td>
</tr>
<tr>
<td>3</td>
<td>0.638</td>
<td>0.94492</td>
<td>0.80431</td>
</tr>
<tr>
<td>4</td>
<td>0.616</td>
<td>0.94492</td>
<td>0.93075</td>
</tr>
<tr>
<td>5</td>
<td>0.383</td>
<td>0.98133</td>
<td>0.93075</td>
</tr>
<tr>
<td>6</td>
<td>0.337</td>
<td>0.98133</td>
<td>0.97836</td>
</tr>
<tr>
<td>7</td>
<td>0.246</td>
<td>1</td>
<td>0.97836</td>
</tr>
<tr>
<td>8</td>
<td>0.205</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

*Table 2.2*: Modal frequencies and participating modal masses of the structure (Translational modes only)
2.3 Mode Shapes

![Mode Shapes](image)

**Figure 2.1:** First three translational modes of the structure in the transverse direction

![Mode Shapes](image)

**Figure 2.2:** First three translational modes of the structure in the longitudinal direction

2.4 Modes Required for Response Spectrum Analysis

Section 12.9.1 of ASCE 7-10 (ASCE, 2010) states that:

“The analysis shall include a sufficient number of modes to obtain a combined modal mass participation of at least 90 percent of the actual mass in each of the orthogonal horizontal directions of response considered by the model.”

As per the above criteria, first two modes in each direction, E-W and N-S, should be considered. It should be noted that rotational modes of vibration has been neglected as there is no mass, and hence no mass participation in rotational direction.
References

ASCE (2010). "Minimum design loads for buildings and other structures." Reston, Va., American Society of Civil Engineers

