Title: Essential Soil-Structure Interaction for Bridge

NAME

Edgar De Los Santos / MIDAS IT – United States
Substructure Training Series

• Session 1: 3D substructure analysis and design

• Session 2: All-In-One Super & Sub Structure Design

• Session 3: Essential Soil-Structure Interaction for Bridge
Content

- What is Soil Structure Interaction
- Types of analysis
- Modeling Functions
- Application of modeling functions
- Results
What is Soil-Structure Interaction?
What is Soil-Structure Interaction?

**SSI:** The phenomenon in which the response of soil and movement of the structure influence each other. When external forces, such as earthquakes, act on these systems, neither structural displacements nor ground displacements are independent of each other.
What is Soil-Structure Interaction?

Soil Structure Interaction is the way in which the structure interacts with the soil. Every structure have a load transfer system to the ground. The amount of load transferred through each foundation depends on the location of the foundation, the flexibility of the foundation and the soil behavior on which it is supported on.
Based on superposition of events, it separates the problem into two simpler parts.

1) **Free Field Analysis:**
The reaction / response of the soil is determined (mainly where the structure will be)

2) **Structural Analysis:**
- The soil can be modeled as spring damper system (impedance) with that response.
  - The detailed structure is designed with the idealization of soil as independent damper springs.
  - Method is more practical for structural engineers

- **Substructure Method**
  - The soil-structure system is modeled and analyzed in one step directly
  - Get response with the two simultaneously.
  - Numerical methods: FEM, FDM
  - This method makes the model too complex to analyze and might include parameters which are difficult to understand for the Structural Engineers.
What is Soil-Structure Interaction?

The pier reaction to the loads depend on the soil and foundation type. The same pier can behave differently with different soil conditions. The force results on the Deck and the Pier depend on whether the flexible foundation effect is considered or not.

Bridge Pier Modeled with Foundation  
Bridge Pier Modeled with a Fixed restrain at the bottom
Boundary Conditions

Nodal boundary conditions

- Constraint for degree of freedom (Supports)
- Elastic boundary element (Spring supports)
  - Point Spring Supports
  - Surface Spring Supports
  - General Spring Supports
- Elastic link element (Elastic Link)
- General Link element (General Link)
  - Element Type
  - Force Type

Element boundary conditions

- Element End Release
  - Beam End Release
  - Plate End Release
- Rigid End Offset distance (Beam End Offset)
- Rigid Link
Boundary Conditions

- Elastic bearings of a bridge structure, which separate the bridge deck from the piers.
- Compression-only Elastic link: the soil boundary conditions.
- Rigid Link: Connects two nodes with an "infinite" stiffness.

Usage
**Boundary Conditions**

- Dampers, base isolators, compression-only element, tension-only element, plastic hinges, soil springs
- Used as linear and nonlinear elements
- Element type: Spring, Dashpot, Spring and Dashpot
- Force type: Viscoelastic Damper, Hysteretic System, Seismic isolators (Lead Rubber Bearing Isolator, Friction Pendulum System Isolator)

**Linear Properties**

<table>
<thead>
<tr>
<th>DOF</th>
<th>Effective Stiffness</th>
<th>Effective Damping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dx</td>
<td>59997997 kips/in</td>
<td>0 kips/sec/in</td>
</tr>
<tr>
<td>Dy</td>
<td>21.5 kips/in</td>
<td>0 kips/sec/in</td>
</tr>
<tr>
<td>Dz</td>
<td>21.5 kips/in</td>
<td>0 kips/sec/in</td>
</tr>
<tr>
<td>Rx</td>
<td>0 in-kips/[rad]</td>
<td>0 n-kips/sec/[rad]</td>
</tr>
<tr>
<td>Ry</td>
<td>0 in-kips/[rad]</td>
<td>0 n-kips/sec/[rad]</td>
</tr>
<tr>
<td>Rz</td>
<td>0 in-kips/[rad]</td>
<td>0 n-kips/sec/[rad]</td>
</tr>
</tbody>
</table>

**Nonlinear Properties**

<table>
<thead>
<tr>
<th>DOF</th>
<th>Properties...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dx</td>
<td></td>
</tr>
<tr>
<td>Dy</td>
<td></td>
</tr>
<tr>
<td>Dz</td>
<td></td>
</tr>
<tr>
<td>Rx</td>
<td></td>
</tr>
<tr>
<td>Ry</td>
<td></td>
</tr>
<tr>
<td>Rz</td>
<td></td>
</tr>
</tbody>
</table>

**Reference Coordinate System**
- Element

**Input Method**
- Beta Angle
- Ref. Point
- Ref. Vector
  - 0

**Joint**

- Joint i
- Joint j

**Local Coordinate Axis**
- x
- y
- z

**General Link Data**
- General Link Property
  - Name: FRB-A
  - Type: Friction Pendulum System

**Elastic Link**

**Rigid Link**

**General Link**

**Usage**
- Element type: Spring, Dashpot, Spring and Dashpot
- Force type: Viscoelastic Damper, Hysteretic System, Seismic isolators (Lead Rubber Bearing Isolator, Friction Pendulum System Isolator)
Surface Spring Supports

This function is mainly used to define a number of elastic supports on surfaces represented by the modulus of spring. For example, if the user wishes to define elastic supports for subgrades of foundations or underground structures, subgrade springs will be automatically entered at each node represented by concentrated stiffness. The function is mainly used to consider elastic support conditions of subgrades in the analysis of foundations or underground structures.

(a) Convert to Nodal Spring
(b) Distributed Spring
Boundary Conditions

- Elastic bearings of a bridge structure, which separate the bridge deck from the piers.
- Compression-only Elastic link: the soil boundary conditions.
- Rigid Link: Connects two nodes with an “infinite” stiffness.
Application of Modeling Functions
Integral Bridge Spring Supports

An integral bridge is one in which the bridge deck and its supporting abutments and piers are integrated without expansion joints to absorb the deformation of the bridge deck using the flexibility of the abutments and piers.

The prime concern in integral bridges is the effects of temperature variations on the deformation of bridge deck. Expansion and contraction of the bridge deck affects the backfill soil adjacent to the abutments. Backfill compaction due to a deck expansion and soil slide due to a deck contraction is repeated. Due to the repeated backfill compaction and soil slide, the modulus of subgrade reaction and the pressure distribution of backfill vary with depth.

A Cycle is the period from a deck expansion to a deck contraction. If cycles are repeated infinitely, the modulus of subgrade reaction of backfill becomes constant. Using the formulation proposed by B.M. Lehane, soil springs can be assigned.
Integral Bridge Spring Supports

In midas Civil, the abutment springs can be applied automatically. The user should insert the soil properties and the springs are assigned automatically by the program. The abutment springs are two types:
- Compression Only: To model the passive support by the back fill
- Footing: The supports are applied to the abutment in the direction of gravity
Integral Bridge Spring Supports

In midas Civil, the abutment springs can be applied automatically. The user should insert the soil properties and the springs are assigned automatically by the program. The abutment springs are two types:
- Lateral Restriction: To model the lateral restraint of the soil in the pile
- Vertical Springs: The stiffness of the elastic linear springs (Verticals) adjacent to the piles.
Pile Spring Supports

Soil Type: Soil Types are classified into Sand / Soft Cray / Stiff Cray. Depending upon the selected Soil Type, stiffness calculation method will be different.

**Ground Level:** Z coordinate of ground

**Pile Diameter** (D)

**Unit Weight of Soil** (γ)

**Earth Pressure Coeff. at rest** (K0): Coefficient of earth pressure at rest

**Coeff. of Subgrade Reaction** (Kh): Modulus of subgrade reaction

**Internal Friction Angle** (Φ): Angle of internal friction of soil

**Initial Soil Modulus** (k1): Constant determined according to the relative density. Determines the stiffness of nonlinear elastic lateral springs for the soils adjacent to piles. Refer to Computation of Points k and m shown below.
Opening Model

File → Open Project
1. Go to the Folder where the model is saved
2. Select the model named: Base Model
3. The model will be opened
Analysis Results
Design as per AASHTO LRFD
Substructure Design
1. Design Condition
   - Design Code: AASHTO-LRFD12
   - Unit System: kips, in
   - Member Number: 336 (PM), 338 (Shear)
   - Material Data: fc = 4.5, fy = 60, fys = 50 ksi
   - Column Height: 72 in
   - Section Property: P1 (No: 6)
   - Rebar Pattern: Total Rebar Area Ast = 41.224 in² (psf = 0.0101)

2. Applied Loads
   - Load Combination 1+ AT (U) Point
     Pu = -0.0000 kips, Muy = 19162.0, Muz = 19162.0, Mc = 27099.2 in-kips

3. Axial Forces and Moments Capacity Check
   - Concentric Max Axial Load Pu
     Prmax = 10733.6 kips
   - Axial Load Ratio Pu/Pu
     Pu/Pr = -0.00000 / 0.00675 = 0.000 < 1.000
   - Moment Ratio
     Muy/Muy = 19162.0 / 47995.1
     Muz/Muz = 19162.0 / 47995.1
     Mc/Mc = 27099.2 / 57675.4

4. P-M Interaction Diagram
   - Graph showing interaction curve with data points and axes for P (kips) and M (in-kips)
Substructure Design
MIDAS Technical Support
http://globalsupport.midasuser.com/

Thank you