Lateral Load Analysis Considering Soil-Structure Interaction

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Overview

- Introduction
- Methods commonly used to account for soil-structure interaction for static loads
  - Depth to fixity
  - Elastic springs at column base
  - Column & caisson with soil springs
- Integrating soil springs within FEM using Midas Civil
- Case Study: 3 span reinforced concrete flume
Introduction

- When designing a structure, the interaction of the structure with the soil is an important consideration.
- In many cases, the absolute and relative stiffness of the soil have a significant impact on the forces experienced by the substructure elements.
- The relative stiffness of the soil from one substructure element to another is also important since it influences the location of the point of zero thermal movement.
  - In general, the point of zero thermal movement moves towards stiffer elements (shorter or thicker columns, stiffer soil, fixed vs. expansion supports, etc.).
  - The location of the point of zero thermal movement is important in determining the movement at each substructure element.
Common methods for static SSI

- Depth to fixity
- Elastic springs at column base
- Soil springs within finite-element model
The Effect of the soil can be approximated by including a portion of the caisson to a certain depth such that a certain aspect of the pile/caisson behavior is approximated.

The depth to fixity can be determined analytically:

- Determine the length of caisson required to cause the pile head translation and rotation to equal that given by an analysis of the pile’s interaction with the soil.
- Complete convergence of both terms may not be possible, so a compromise may be required, such as choosing a pile length that the model using the depth to fixity and the model considering the soil structure interaction (such as LPile) are within 5% to 10% of each other for both parameters.

Can also be approximated empirically based on soil properties:

- AASHTO Equations C10.7.3.13.4-1 and C10.7.3.13.4-2 can be used to obtain a very approximate depth to fixity which can be used.
Advantages
- Relatively simple to implement
- Can obtain reasonably accurate structural behavior

Disadvantages
- Iteration is required
- Convergence can only reliably be obtained for one parameter at a time
- Unrealistic moment and shear along caisson length (maximum moment at bottom of caisson instead near the top, as is the case in reality)
Elastic Springs at Column Base

- Elastic springs can also be included at the base of the columns based on the results from an LPile analysis.
- This analysis can be an improvement over an analysis using the depth to fixity.
  - The stiffness of the spring for each degree of freedom can be specified, thus the rotation and translation in each direction can be indicated appropriately.
- This method also requires iteration since the translation and rotation is not necessarily linear with respect to lateral load.
Elastic Springs at Column Base

- **Advantages**
  - More realistic modeling than model using depth to fixity
  - Spring stiffness can be specified for each degree of freedom

- **Disadvantages**
  - Iteration is required between FEM and soil-structure analysis software
  - No information is available from the FEM concerning shear and moment in the pile or caisson
To avoid the iteration involved with the other two methods, soil springs can be integrated directly into the FEM.

Midas Civil makes this simple, using the surface spring feature:
- Requires only the soil subgrade modulus.

Using this method, the entire pile/caisson length can be entered along with corresponding surface springs representing the soil.

The shear and moment along the pile or caisson can be obtained directly from the FEM.

The structural behavior, including the soil-structure interaction is fully considered.

Need to ensure an adequate number of elements are implemented to ensure peak shear and moment are captured.
Soil springs within finite-element model

- **Advantages**
  - No iteration is required
  - Caisson shear and moment can be obtained directly from FEM
  - Accuracy of structural model at least as good as with other two options

- **Disadvantages**
  - Somewhat more work to develop model
  - Need to know the modulus of subgrade reaction for the various soil strata
When utilizing soil springs in Midas Civil, the structural model is created (either the substructure unit of interest, or the structure as a whole), including the deep foundation.

The boundary conditions for lateral loading are then created using the “Surface Spring” option under “Boundaries” (see next slide).

Within the Surface Spring dialogue box, the type of element upon which the soil spring is to be applied can be chosen, along with the type of spring desired (surface spring or point spring).

The required parameters can then be entered, including the modulus of subgrade reaction.
Using Soil Springs in Midas Civil
Once the model and boundary conditions have been entered, the loading can be applied and results obtained, including the point of zero thermal movement and moments along the columns and deep foundation elements.
Validation of Midas Results

Before using the results directly from Midas Civil, I verified the accuracy of the model using LPile.

- Using the elastic static lateral subgrade modulus values given in the geotechnical report:
A simple case study will now be illustrated

- 199' – 8" long flume structure
- Three span structure with 7' cantilevers on each end
  - Span lengths = 61', 65' – 2", 61' (chosen to work around existing drilled shafts)
- 8' deep reinforced concrete tub girder (1' thick)
- Piers designed such that most superstructure loads applied directly to columns
- 42" diameter columns
- 48" diameter caissons
- Variable soil profile considered (simplified for this presentation)
- Lateral loads applied as per AASHTO LRFD Specifications