Structural Response to Pile Foundation Stiffness in FEM Stability Analysis

Master’s thesis: The effect of modeling lateral stiffness of pile foundations on numerical analyses of structural frames

Aalto university, 2018

Goals of the thesis

• Analyze the structural sensitiveness to the variation on the pile foundation stiffness models in FEM stability analysis
Goals of the thesis

• Analyze the structural sensitiveness to the variation on the pile foundation stiffness models in FEM stability analysis

• Reduce the usage of raking piles by relying on lateral resistance of piles

• Suggest an improved interaction between structural and geotechnical engineers
Goals of this presentation

• Show how simplifications in pile foundation stiffness models affect structural stability analysis

• What are the risks of simplifications in pile foundation stiffness
Goals of this presentation

- Show how simplifications in pile foundation stiffness models affect structural stability analysis
- What are the risks of simplifications in pile foundation stiffness
- How structural and geotechnical engineers can minimize the risks

Models used in the analysis

<table>
<thead>
<tr>
<th>Model 01</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness calculation</td>
</tr>
<tr>
<td>Group interaction</td>
</tr>
<tr>
<td>Spring distribution</td>
</tr>
</tbody>
</table>
### Models used in the analysis

<table>
<thead>
<tr>
<th></th>
<th>Model 01</th>
<th>Model 02</th>
<th>Model 03</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness</td>
<td>-</td>
<td>Subgrade reaction approach</td>
<td>P-y method with 100 cycles</td>
</tr>
<tr>
<td>calculation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group interaction</td>
<td>-</td>
<td>Front row resistance</td>
<td>All piles</td>
</tr>
<tr>
<td>Spring</td>
<td>-</td>
<td>Middle of pile group</td>
<td>Along the pile shaft</td>
</tr>
<tr>
<td>distribution</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Models used in the analysis

<table>
<thead>
<tr>
<th>Model 01</th>
<th>Model 02</th>
<th>Model 03</th>
<th>Model 04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness</td>
<td>Subgrade reaction approach</td>
<td>P-y method with 100 cycles</td>
<td>P-y method with 100 cycles</td>
</tr>
<tr>
<td>calculation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>Front row resistance</td>
<td>All piles</td>
<td>All piles</td>
</tr>
<tr>
<td>interaction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td>Middle of pile group</td>
<td>Along the pile shaft</td>
<td>On top of each pile head</td>
</tr>
<tr>
<td>distribution</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pile group interaction

<table>
<thead>
<tr>
<th>Author</th>
<th>Sand type</th>
<th>s/b</th>
<th>Comment</th>
<th>p-multiplier</th>
<th>p-multiplier</th>
<th>p-multiplier</th>
<th>p-multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown et al.</td>
<td>Medium dense over stiff clay</td>
<td>3</td>
<td>-</td>
<td>0.8 - 1.0</td>
<td>0.4</td>
<td>0.35</td>
<td>-</td>
</tr>
<tr>
<td>McVay et al.</td>
<td>Loose and medium dense</td>
<td>3</td>
<td>-</td>
<td>0.8</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Reese et al.</td>
<td>No classification</td>
<td>3</td>
<td>*1</td>
<td>0.86</td>
<td>0.59</td>
<td>0.63</td>
<td>-</td>
</tr>
<tr>
<td>Al-Shamary et al. (2018)</td>
<td>No classification</td>
<td>3</td>
<td></td>
<td>0.38</td>
<td>0.46</td>
<td>0.39</td>
<td>-</td>
</tr>
</tbody>
</table>
Results obtained - internal forces of piles

<table>
<thead>
<tr>
<th>Results</th>
<th>Model 01</th>
<th>Model 02</th>
<th>Model 03</th>
<th>Model 04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal forces (N, V, M)</td>
<td>No pile results</td>
<td>N</td>
<td>N, V, M</td>
<td>N, V</td>
</tr>
</tbody>
</table>

Bending moment Model 02 and 04

Results obtained – foundation deformation

<table>
<thead>
<tr>
<th>Results</th>
<th>Model 01</th>
<th>Model 02</th>
<th>Model 03</th>
<th>Model 04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal forces (N, V, M)</td>
<td>No pile results</td>
<td>N</td>
<td>N, V, M</td>
<td>N, V</td>
</tr>
<tr>
<td>Foundation deformation</td>
<td>None</td>
<td>Up to 6.3 mm</td>
<td>Up to 1.7 mm</td>
<td>Up to 1.2 mm</td>
</tr>
</tbody>
</table>

Model 02 (scale 0…6,3mm)  
Model 03 (scale 0…1,7mm)  
Model 04 (scale 0…1,2mm)
Results obtained – load transfer on bearing structure

Resultant of shear force in wall 09

Results obtained – deformation and forces

- Lateral loading from structural deformation

Vertical deformation
Results obtained – deformation and forces

- Lateral loading from structural deformation

Vertical deformation

Strut and tie mechanism

Time for reflection

Which one is accurate?
Time for reflection

Which one is accurate?

How accurate will be the load transfer in the stiffening elements?

Answer: depends on how accurate is your foundation model
Soil-Structural interaction (SSI)

- General overview

- Soil response under different loads
  - Dynamic
  - Sustained
  - Short-term static
  - Cyclic

Steward, J.P et. al. (2012)
Soil-Structural interaction (SSI)

• Cyclic response

Pile utilization factor

• Should it be calculated all piles in Ultimate Limit State?

  – Maybe not! Pile stiffness is dependent on the load it was calculated to carry.
Pile utilization factor

- Should it be calculated all piles in Ultimate Limit State?
  - **Maybe not!** Pile stiffness is dependent on the load it was calculated to carry.
  - Optimal to use loads closer to what it is actually carrying in the FEM calculations

How to reduce risks and make a more accurate design?

*Increase communication between Structural and geotechnical engineering*

- Exchange needed and relevant data before design
  - What is needed in the other field to make accurate calculations?
How to reduce risks and make a more accurate design?

Increase communication between Structural and geotechnical engineering

- Exchange needed and relevant data before design
  - What is needed in the other field to make accurate calculations?

- Exchange recommendations and information about structure and soil.
  - Loadings, deflections, special limitations, type of analysis and others.

- Regular meetings and verifications in later design stages to verify results
How to reduce risks and make a more accurate design?

Increase communication between Structural and geotechnical engineering

• Exchange needed and relevant data before design
  – What is needed in the other field to make accurate calculations?

• Exchange recommendations and information about structure and soil.
  – Loadings, deflections, special limitations, type of analysis and others.

• Regular meetings and verifications in later design stages to verify results

Advantages
• Avoid overusing raking piles

• Avoid under or over design and increase reliability of design
How to reduce risks and make a more accurate design?

Increase communication between Structural and geotechnical engineering

- Exchange needed and relevant data before design
  - What is needed in the other field to make accurate calculations?

- Exchange recommendations and information about structure and soil.
  - Loadings, deflections, special limitations, type of analysis and others.

- Regular meetings and verifications in later design stages to verify results

Advantages

- Avoid overusing raking piles
- Avoid under or over design and increase reliability of design
- Create a more economical foundation solutions for the customer

Some reference and contact information

- Master’s thesis (Aalto University): The effect of modeling lateral stiffness of pile foundations on numerical analyses of structural frames (Publication date: 01.11.2018)

- Tiago de Souza Magnus
  - tiago.magnus@sweco.fi