Dynamic Soil-Structure Interaction

With three case studies:

- Silo Building Zürich (118 Meter)
- Azadi Hotel Tehran (86 Meter)
- MIT Green Building (83 Meter)

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Problem definition of dynamic unbounded medium-structure-interaction analysis

Wolf J. P., Ch. Song: Finite-Element Modelling of Unbounded Media, 1995
Case Studies

Silo Zürich 118 Meter

Azadi Hotel Tehran 86 Meter

MIT Green Building 83 Meter
Substructure method: Physical interpretation of basic equations of motion in total displacements with effective foundation input motion

Wolf J. P.: Dynamic Soil-Structure Interaction, 1985
Model with one dynamic degree of freedom

Wolf J. P.: Dynamic Soil-Structure Interaction, 1985
### Silo Zürich, roof displacements in cm, Swiss SIA earthquake

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Structural displacement</td>
<td>8 cm</td>
</tr>
<tr>
<td>Soil displacement</td>
<td>2 cm</td>
</tr>
<tr>
<td>Displacement due to rocking</td>
<td>11 cm</td>
</tr>
<tr>
<td>Total displacements</td>
<td>21 cm</td>
</tr>
</tbody>
</table>

### MIT-Building 54, roof displacement in cm, Boston earthquake

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Structural displacement</td>
<td>20 cm</td>
</tr>
<tr>
<td>Soil horizontal displacement</td>
<td>2 cm</td>
</tr>
<tr>
<td>Displacement due to rocking</td>
<td>8 cm</td>
</tr>
<tr>
<td>Total displacements</td>
<td>30 cm</td>
</tr>
</tbody>
</table>
Properties of equivalent one-degree-of-freedom system, varying slenderness ratio

Wolf J. P.: Dynamic Soil-Structure Interaction, 1985
Example: Determination of equivalent frequency for MIT Green Building

\[ \bar{s} = \frac{\omega_s h}{c_s} = \frac{2\pi}{1.3978} \times \left( \frac{2/3 \times 83.7}{207.85} \right) = 1.2 \]

\[ \bar{h} = \frac{h}{a} = \frac{h}{\sqrt{\frac{2L \times 2B}{\pi}}} = \frac{2/3 \times 83.7}{\sqrt{\frac{34 \times 20.5}{\pi}}} = 3.74 \]

\[ \bar{m} = \frac{m}{\rho a^3} = \frac{12238 \times 1000}{2034 \times \left( \frac{34 \times 20.5}{\pi} \right)^3} = 1.82 \]

\[ \frac{\bar{\omega}^2}{\omega_s^2} = \frac{1}{1 + \frac{m s^2}{8} \left[ \frac{2 - \nu}{\bar{h}^2} + 3(1 - \nu) \right]} = 0.589 \Rightarrow \bar{\omega} = \sqrt{0.589 \times \frac{2\pi}{1.3978}} = 3.45 Hz \]

\[ \tilde{\xi} = \frac{\bar{\omega}^2}{\omega_s^2} \xi + \left(1 - \frac{\bar{\omega}^2}{\omega_s^2} \right) \xi_g + \frac{\bar{\omega}^3}{\omega_s^3} \frac{s^3 m}{\bar{h}} \left[ 0.036 \frac{2 - \nu}{\bar{h}^2} + 0.028(1 - \nu) \right] \approx 0.055 \]
Determination of soil dynamic stiffness: dampers, springs

a) Rigorous Models
   • FEM
   • Boundary Element Method, BEM
   • SBFEM

b) Approximate Models
   • Cone
   • Lumped Mass Model
Overview of Zürich City
## Technical data of Silo in Zürich

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>118 m</td>
</tr>
<tr>
<td>Floorplan dimensions</td>
<td>22.40 m x 30.0 0m</td>
</tr>
<tr>
<td>Cubic</td>
<td>81'430 m$^3$</td>
</tr>
<tr>
<td>Roof displacement</td>
<td>direction west – east</td>
</tr>
<tr>
<td></td>
<td>direction north – south</td>
</tr>
<tr>
<td></td>
<td>± 17 cm</td>
</tr>
<tr>
<td></td>
<td>± 21 cm</td>
</tr>
<tr>
<td>First eigenfrequency</td>
<td>0.32 HZ</td>
</tr>
<tr>
<td>Excavation volume</td>
<td>with piles</td>
</tr>
<tr>
<td></td>
<td>5'000 m$^3$</td>
</tr>
<tr>
<td>Piles</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>diameter 1.50 m</td>
</tr>
<tr>
<td></td>
<td>length 40 – 45 m</td>
</tr>
<tr>
<td>Beton volume</td>
<td>18'000 m$^3$</td>
</tr>
<tr>
<td>Steel volume</td>
<td>2'700'000 kg</td>
</tr>
</tbody>
</table>
Existing silo: 38 meter high
50 years old

Existing silo (gray)
New silo (green)
Typical floor plan view
Foundation of the existing and of the new silo

Existing silo: Mat foundation

New silo: Pile foundation with 49 piles and two pile cops 4.2 Meter
Site layers and the wave pattern
• Sight from top of silo to the ground
• Distribution of silo cells, 118 Meter
• Construction stage, August 2015
• Construction work at severe conditions, safety net and ropes
Zürich Riverbank, August 2015
• Reinforcement
• Placing the reinforcement at 110 Meter
• 24 hours work (3 shifts, 8 hours)
• 81 Meter at in-situ concrete in 21 days
• 4.1 Meter per 24 hours
Top of silo, August 2015
Photo from top of silo:

River with train viadukt
Soil Damping calculated with CONAN using Cone Models (Wolf, ETH)
References


11. T. Hughes, Stanford lecture notes on finite element techniques, Stanford University, Stanford CA, USA, 1981.