IMPEDANCE MODELING: AN EFFICIENT MODELLING METHOD FOR PREDICTION OF BUILDING FLOOR VIBRATIONS

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Structures Congress 2012
Thursday March 29th, 2012
Significance of the Research

• Sources of Measured Excitation
  – Running Trains / Subways
  – Vehicular Traffic

• Vibration propagates from ground into the foundation and into the structure

• Impacts due to Vibrations
  – Precision manufacturing facilities
  – Laboratories
  – Human comfort
Significance of the Research

• Preventive measures need computationally efficient and cost effective predictive methods

• Available predictive tools are:
  – Empirical models
  – Finite element models
  – Impedance models
Background and Current Research

• Sanayei et al. (2011) developed and validated an impedance based modeling technique to predict floor vibrations in buildings.

• For a scale model building, axial vibrations was induced at the base of the center column over frequency range of 100 Hz to 5 kHz. It corresponds to 10 to 500 Hz for a full scale building.

• Predicted vibration responses are compared between the FE model and the impedance model.

• Model response accuracy and computational time are compared for these two models.
Four Story 1/10 Scale Model Building
Design of Scale Model Building

• Zhao (2009) revised the design of a 4-story scale model building. The 1/10 scale model building is 2 bays by 2 bays.

• Scale Model Description
  – Columns: 80/20 Aluminum
  – Slabs: Medium Density Fiberboard (MDF)
  – Connections: 8 L-shape brackets (4 above & 4 below) slab to ensure moment connection between slab and column (modeled as lumped masses)
  – Material properties of MDF were verified by Hughes (2008) & Zhao (2009)
Finite Element Modeling

Three models with different mesh sizes have been constructed using the finite element program.

Model A: Coarse Mesh

Model B: Medium Mesh

Model C: Fine Mesh
## Finite Element Modeling

### Finite Element Model:

<table>
<thead>
<tr>
<th>Component Size</th>
<th>Model A Coarse</th>
<th>Model B Medium</th>
<th>Model C Fine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column Elements [in]</td>
<td>1.0</td>
<td>0.5</td>
<td>0.25</td>
</tr>
<tr>
<td>Beam Elements [in]</td>
<td>12.0</td>
<td>3.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Slab Elements [in]</td>
<td>12.0 x 12.0</td>
<td>3.0 x 3.0</td>
<td>1.5 x 1.5</td>
</tr>
<tr>
<td>Total No. of Elements</td>
<td>698</td>
<td>2,828</td>
<td>8,728</td>
</tr>
</tbody>
</table>

The responses from FE models for each floor have been compared to the measured floor vibration responses from the physical experiment.
Comparison of FE Models A (Coarse), B (Medium) and C (Fine)

Selected: Model C
Impedance Modeling: Column

- Modeled as a column with axial wave propagation

- Dynamic stiffness matrix (2 x 2)

\[
[k_{col}] = \frac{EA\beta}{\sin(\beta L)} \begin{bmatrix} \cos(\beta L) & -1 \\ -1 & \cos(\beta L) \end{bmatrix}
\]

where wave number is

\[
\beta = \frac{2\pi}{\lambda} = \frac{\omega}{c_L} = \omega \sqrt{\frac{\rho}{E}}
\]

\(\lambda\) is the wave length.

\(c_L\) is the axial wave speed.
Impedance Modeling: Floor Slab

Each floor slab is modeled as a lumped impedance in the column. Kirchhoff’s theory is used for modeling of thin infinite plates.

– Only bending deformation considered

– No transverse shear and rotary inertia is considered

– Point force impedance of slab used at connection to columns:

\[ Z_{\text{Slab}} = 8\sqrt{D} \sqrt{\rho t} = 8t^2 \sqrt{\frac{\rho E}{12(1-v^2)}} \]

– Dynamic mass of the plate is:

\[ m_{\text{dyn}} = Z_{\text{slab}} / j\omega \]
Impedance Modeling: System

Assumptions:

- System is modeled as vibration propagating axially in column and as transverse bending waves in floor slabs.
- Bending vibrations in upper columns is significantly attenuated by lower floors (Conroy, 2008).
- Vibrations reaching upper floors is due to axial propagations in columns (Conroy, 2008).
- Complex modulus is used to represent damping

\[ E_c = E(1 + j\eta) \]

- Dynamic equilibrium for harmonic excitation at frequency \( \omega \) is:

\[ \left[ K_{col} - \omega^2 M_{dyn} \right] \{U\} = \{F\} \]
Comparison:
FE Model C and Impedance Model with Measured Response

Excellent 3-way match!

Which model to use?
Finite Element vs. Impedance

### Accuracy in Higher Frequency Ranges

<table>
<thead>
<tr>
<th></th>
<th>FE Model A Coarse</th>
<th>FE Model B Medium</th>
<th>FE Model C Fine</th>
<th>Impedance Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td></td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

### Computational Efficiency

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>FE Model A Coarse</th>
<th>FE Model B Medium</th>
<th>FE Model C Fine</th>
<th>Impedance Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Elements</td>
<td>698</td>
<td>2,828</td>
<td>8,728</td>
<td>8</td>
</tr>
<tr>
<td>No. of DOFs</td>
<td>4,026</td>
<td>16,734</td>
<td>52,038</td>
<td>5</td>
</tr>
<tr>
<td>Computation Time</td>
<td>00:12:53</td>
<td>01:12:39</td>
<td>06:12:24</td>
<td>00:00:20</td>
</tr>
</tbody>
</table>
Conclusions

1. Both the FE fine mesh model and the impedance model matched well with the measured data. The coarse mesh FE model had difficulties in accurately predicting the response at higher frequencies.

2. The impedance model had a comparable accuracy with the fine mesh FE model. Although the FE model with a fine mesh predicted an accurate response in the high frequency range, it required a large increase in computation time.

3. The impedance model is computationally efficient as compared to the FE model and results in highly accurate response predictions.
Future Work

• Full-scale testing:
  – Validation of the mathematical model for full-scale buildings
  – Estimation of the effects of additional structural components and foundations on vibration propagation
  – Prediction of the model using Mindlin thick plate theory.
Acknowledgements

• Acentech, Inc.
• Dr. Babak Moaveni, Professor, Tufts University
• Dr. Brian Tracey, Professor, Tufts University
• Paul L. Rosenstrauch, Graduate Student, Tufts University
Thanking You

Questions?