Wave Propagation in Buildings as Periodic Structures: Timoshenko Beam with Slabs Model and its Application to Structural System Identification and Health Monitoring

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Vision – all these buildings have a SHM system
Motivation

- **Simple beam models** - usually used to study wave propagation in building structures and for **structural system identification**
- Work well in the **longer period range**, where such models are valid
- Can detecting **overall changes** in the structural stiffness
- Can also detect variation of stiffness and damage in **parts of the structure** (e.g. group of floors).
Example – Fit of 4-layer Timoshenko beam

Objective

- Detection of **localized damage**:
  - Requires **more detailed models**, and
  - Fitting over **a broader frequency band**

- Wave propagation is **dispersive** in composite structures (made of different elements and materials)

- Therefore **wave dispersion needs to be understood**

- Towards this goal, we have analyzed several dispersive beam models
  - Shear beam – nondispersive (frame structures)
  - Timoshenko beam - dispersive due to bending deformation - (RC structures with shear walls)
  - Timoshenko beam with slabs – dispersive at higher frequencies
Los Angeles 54-story Office Building

54-story, moment resisting perimeter steel frame

Behaves like shear beam, more so in the EW direction

CSMIP Station 24629

(Rahmani and Todorovska, EESD 2014)
Millikan Library – Evidence of dispersion

9-story, RC structure

Yorba Linda, 2002, M=4.8, R=40 km

(Rahmani and Todorovska, SDEE 2013)
Dispersion due to Bending

- Timoshenko beam model of Millikan library
- Shear, bending, rotatory inertia (Timoshenko, 1921)

(Ebrahimian and Todorovska, J. Eng. Mech., ASCE 2014)
Dispersion in a Timoshenko Beam Model

\[ c_L = \sqrt{\frac{E}{\rho}}; \quad c_S = \sqrt{\frac{G}{\rho}}; \quad r_g = \sqrt{\frac{I}{A}}; \quad R = \frac{G}{E} = \frac{c_S^2}{c_L^2} \]

(Ebrahimian and Todorovska, J. Eng. Mech., ASCE 2014)
**Additional Dispersion due to Scattering from the Floor Slabs**

\[ \alpha^* = \frac{\text{mass of slab}}{\text{total floor mass}} \]

- Model of Millikan Library - NS resp.
- Model parameters obtained by LSQ fit of Impulse Responses
- Different curves correspond to different ratio between mass of slabs and mass of the "soft part" of the floor (\( \alpha \))

(Ozmutlu, Ebrahimian and Todorovska, 2015; to be submitted)
Publications:


... more on the project web site at
www.usc.edu/dept/civil_eng/Earthquake_eng/Earthquake_damage_detection_NSF_2008/
Acknowledgements

- Part of this work was supported by a grant from U.S. National Science Foundation (CMMI-0800399).
- Aydin Ozmutlu’s visit to USC was supported by TUBITAK
- Sources of strong motion data:
  for Los Angeles 54-story building the data was obtained from Engineering Centre for Strong Motion Data (www.strongmotioncenter.org/);
  for Millikan Library, the data was obtained from U.S. Geological Survey Strong Motion Instrumentation Project (http://nsmp.wr.usgs.gov/).
Thank You!