Structural Parameter Estimation of Complex Connections Using Modal Data

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Introduction

The mechanical properties of joints may impact a system's static and dynamic behavior. Since connections are usually complex, modeling their geometric details could take time and effort. Thus, joints of structures are often overlooked in model creation and calibration. Therefore, reliable analytical modeling of in-service structures requires accurate and efficient parameter estimation of the connections in their simplified models. However, joints are physically small parts of a system, and parameter estimation techniques may not be sufficiently sensitive to the variations of connections' mechanical properties. This research examines the finite element model updating of a laboratory steel grid, focusing on the structural parameter estimation of its complex connections using modal data. The mechanical properties of the joints are parametrized by added mass and reduced rigidity. Therefore, several modified models with different combinations of heavier semi-rigid joints are developed. Each model is updated using two modal-based error functions, and the most representative updated model is selected. The results demonstrate how the grid modal outputs are influenced by updating the mass and stiffness of its connections. The updated models can efficiently simulate the structural behavior of the grid with increased confidence and reliability.

UCF Grid

- Complex Connections
- Instrumented by Accelerometers
- Representation of Short- to Medium-Span Bridges

Photo: Courtesy of UCF

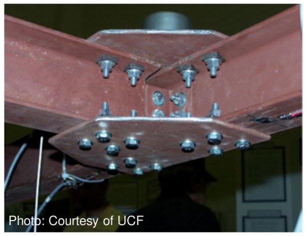


Photo: Courtesy of UCF

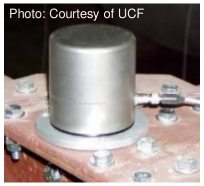
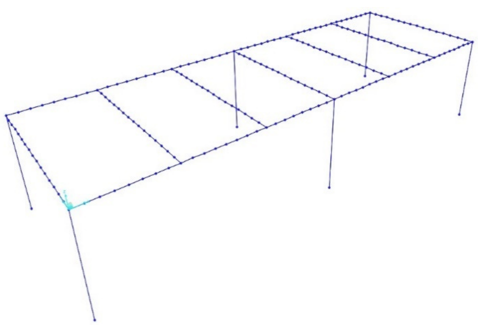
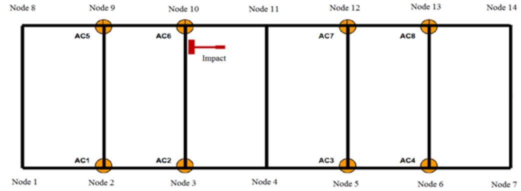


Photo: Courtesy of UCF

Analytical Modeling



Instrumentation and Impact Test



Modal-Based Error Functions

Stiffness-Based Error Function

$$\mathbf{E}_{ms}(\boldsymbol{\theta}) = \left[\mathbf{K}(\boldsymbol{\theta}) - \omega^2 \mathbf{M}(\boldsymbol{\theta})\right]\boldsymbol{\phi}$$

Flexibility-Based Error Function

$$\mathbf{E}_{mf}(\boldsymbol{\theta}) = \left[\omega^2 \mathbf{K}^{-1}(\boldsymbol{\theta})\mathbf{M}(\boldsymbol{\theta}) - \mathbf{I}\right]\boldsymbol{\phi}$$

$\boldsymbol{\theta}$ Vector of Updating Parameters

$\mathbf{K}$ Stiffness Matrix

$\mathbf{M}$ Mass Matrix

ω Natural Frequency

$\boldsymbol{\phi}$ Mode Shape

Results

Case No.	Stiffness of Joints	Mass of Joints
Case 1	✓	×
Case 2	×	✓
Case 3	✓	✓

Case No.	Stiffness of Joints	Mass of Joints
Units	kN.m/rad	kg
Case 1	6636	×
Case 2	×	1.3
Case 3	6636	0.3

Analysis Notes

- Deterministic Model Updating
- Modal Analysis
- Hammer Impact Test
- Mode Extraction from Measured FRFs
- First 12 Modes of Vibration
- Excluded Modes: Modes 7-11

Conclusions

- Asymptotic nature of partial fixities overshadows estimation of nodal mass values.

- Multiple-step parameter estimation can enhance the parameter estimation procedure.

- Inspection of objective function graphs is essential to ensure ignoring local minima for the flexibility-based error function analyses.

- Mode selection for the parameter estimation should be determined based on the instrumentation layout.

Acknowledgment

Bibliography

Automated structural parameter estimation of semi-rigid complex joints in a benchmark laboratory steel grid by experimental modal analysis, Milad Mehrkash and Erin Santini-Bell, Journal of Vibration and Control, 2024.