Time evolution of the modal parameters of a five-story building using strong motion data

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Presenter: Dr. Xiang Wang
University of California, San Diego
Outline

- BNCS project
- Measured and observed responses
- System identification
- Concluding remarks
**Scope:** Study the seismic response of the building structure and NCSs and their dynamic interaction at different levels of seismic excitation

**Test building:** Full-scale 5-story reinforced concrete (RC) building fully equipped with nonstructural components and systems

**Building tested under base-isolated and fixed-base configurations**

![Diagram of building structure and seismic response](image)
Base-isolators and Component tests

- Based on component tests (ASCE 7):
  
  **Effective stiffness**
  \[ k_{\text{eff}} = \frac{|F^+| + |F^-|}{\Delta^+ + \Delta^-} \]

  **Effective damping ratio**
  \[ \xi_{\text{eff}} = \frac{E_{\text{loop}}}{\pi \xi \left(|\Delta^+| + |\Delta^-|\right)^2} \]
<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
<th>Name</th>
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<tr>
<td>April 16</td>
<td>Canoga Park (1994 Northridge)</td>
<td>BI:1-CNP100</td>
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<td>LA City (1994 Northridge)</td>
<td>BI:2-LAC100</td>
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<td>April 17</td>
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<td>San Pedro (2010 Maule -Chile)</td>
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<td>ICA 50% (2007 Pisco-Peru)</td>
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<td>ICA 140% (2007 Pisco-Peru)</td>
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Seismic Input Motions

- 7 Seismic tests
- WN tests before and after each seismic test
- Ambient vibrations recorded continuously from April 14-30, 2012
Seismic Input Motions
Responses
Global Response
Isolation System Response
System Identification

\[ x_{k+1} = A_d x_k + B_d u_k + w_k \]
\[ y_k = C_d x_k + D_d u_k + v_k \]
**System Identification**

- **Method:** Deterministic-Stochastic Subspace Identification

\[
\begin{align*}
\mathbf{x}_{k+1} &= \mathbf{A}_d \mathbf{x}_k + \mathbf{B}_d \mathbf{u}_k + \mathbf{w}_k \\
\mathbf{y}_k &= \mathbf{C}_d \mathbf{x}_k + \mathbf{D}_d \mathbf{u}_k + \mathbf{v}_k
\end{align*}
\]

- State (Process) eq.
- Measurement eq.

Eigenvalues of \( \mathbf{A}_d \): \( \mu_i = \exp(\lambda_i \Delta t) \Rightarrow \lambda_i = \ln(\mu_i) / \Delta t \)

Eigenvalues of \( \mathbf{A}_d \equiv \) Eigenvectors of \( \mathbf{A}_c = \mathbf{\Psi} \)

- \( \Phi = \mathbf{C}_d \mathbf{\Psi} \)
- \( f_i = \frac{|\lambda_i|}{2\pi} \)
- \( \xi_i = -\frac{\text{Re}(\lambda_i)}{|\lambda_i|} \)
System Identification

- **Windowing approach**: LTI response for each short-time window
  
  (Tobita et al. 1988, Moaveni and Asgarieh 2012, Loh et al. 2013)

Length of the windows and overlap:

- ✓ based on fixed-length windows (5 sec with and without overlap)
- ✓ based on the energy distribution of the input (using the Arias Intensity)
- ✓ **the minimum length window with and without overlap (50%)**

\[ s_{\text{min}} = 2i(r + m + 1) = 2 \times 45(1 + 6 + 1) = 720 \text{ samples} \rightarrow 720/200Hz = 3.6 \text{ s} \]

\[ i = 45 \# \text{ block rows of Hankel matrix (following Rainieri and Fabbrocino, 2014)} ; r = 1 ; m = 6 \]
For each short-time window, stabilization diagrams are used to determine the physical modes and the order of the SS model (non-recursive approach)

\[
|f_r - f_s|/f_s \leq 2\% \quad ; \quad |\xi_r - \xi_s|/\xi_s \leq 10\% \quad ; \quad \left(1-\text{MAC}_{\phi_r,\phi_s}\right)100 \leq 2\%
\]
System Identification

![System Identification Diagram](image-url)
- Comparison between $f_{1-L}$: minimum from SID ($f_{1-L}^{\text{SID}}$) and approximated using component test data ($f_{1-L}^{\text{app}}$):

$$f_{1-L}^{\text{app}} = \frac{1}{2\pi} \sqrt{\frac{k_{\text{eff total}}^{\text{est}}}{W}}$$

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**Graphical Representation**

- Graph showing the comparison between $f_{1-L}^{\text{SID}}$ and $f_{1-L}^{\text{app}}$.
- The graph includes data points for BI1 to BI7.

**Equation**

$$k_{\text{eff total}} = 3792.2^2 - 16703\gamma^2 + 27820\gamma^2 - 21257\gamma + 9425$$

$R^2 = 0.999$
Concluding Remarks
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- Full-scale base-isolated R/C building structure outfitted with a wide range of NCSs
- Structure tested at different levels of excitation (AV, WN, seismic)
- Realistic seismic excitation
- Tracking of modal properties during the seismic tests
  - Good agreement between different methods and at different levels of excitation
  - Large equivalent damping ratios for isolation mode
- Effect of the amplitude of the excitation
- Mullin’s effect observed
Thank you for your attention!

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