Time-Lapse Changes in Seismic Response of a Building over 20 Years due to Earthquakes and Aging

Nori Nakata (University of Oklahoma)

Toshihide Kashima (Building Research Institute, Japan)
Structural health monitoring

Millikan library @ Caltech

Clinton et al., BSSA, 2006
Building for this study

- **8-story building in Tsukuba, Japan**
- **Steel reinforced concrete building**
  - Rigid frame
- **11 sensors** in the building, 3C + 3 (surface) and 4 (borehole)
- Recording starts when the building built (1998) = 20 years
- More than **1,600 earthquakes** have been recorded. ($M_{\text{JMA}} = 0.0\sim9.0$)
Building for this study

Fundamental mode: ~1.5 Hz
Deconvolved wavefields

\[ u(z, \omega) \]
\[ \frac{u(z, \omega)}{u(8, \omega)} \]

Nakata et al., BSSA, 2013

Transfer function in time domain
- Wide frequency range
- Wavefield (both phase and amplitude)

March 26, 1999, 8:31AM
M_{JMA} 5.0, Depth 59 km
Distance 60 km (Ibaraki-Oki)
Deconvolved wavefields

\[ \frac{u(z, \omega)}{u(8, \omega)} \]
Deconvolved wavefields

\[
\frac{u(z, \omega)}{u(8, \omega)}
\]
Time-lapse changes at the base floor

Tohoku EQ
Velocity changes over the years
Velocity changes over the years

\[ \text{Vel} = -19.4 \ln(\text{year} - 1998) + 98.78 \]
Velocity changes over the years

\[ \text{Vel} = -19.4 \ln(\text{year} - 1998) + 98.78 \]

Aging?
- wind
- temperature
- humidity
- rain

Andrade et al. (1999, CCR)
Velocity changes over the years

20~25%
Velocity changes over the years

20~25%

20~25%
Consistent with another building

Nakata et al., BSSA, 2015
Zoom-in on Tohoku EQ
Zoom-in on Tohoku EQ
Compared with borehole data

**Building**

- North-South
- East-West

**Borehole**

- North-South
- East-West

Graphs showing velocity change (% of year) from 2000 to 2015.
Velocity change vs. Drift
Velocity change vs. Drift
... according to the largest earthquakes

Mar 11, 2011
May 05, 2008
Oct 06, 2004
May 26, 2003
Jul 21, 2000
Transfer functions in the time domain

Nakata et al., BSSA, 2013
Transfer functions in the time domain

\[ D(z, \omega) = \frac{u(z, \omega)}{u(1, \omega)} \]

\[ D(z, t) = \frac{4\pi c}{H} \sum_{l=0}^{\infty} (-1)^l e^{-\gamma \omega_l t} \sin(\omega_l t) \cos \left( \omega_l \frac{H - z}{c} \right) \]

**Assumptions**
- 1D structure (WKBJ)
- Independent components
- Mode shape

**Mode summation**

**Boundary condition**

**Damping**

**Resonance in time**

Nakata et al., BSSA, 2013
... works well for tall building

52-story building

Deconvolution with top floor

Amplitude ratio at each floor

Velocity change vs. PGA

![Graph showing velocity change vs. PGA](image)
... according to the largest earthquakes

- Mar 11, 2011
- Jun 14, 2002
- Apr 10, 2000
- Mar 26, 1999