NGA high-pass filters remove important real signals; simple tilt correction is preferable.

B. Roh¹, K. Buyco², T. Heaton³

¹Graduate Student, Dept. of Mechanical and Civil Engineering, California Institute of Technology
²Graduate Student, Dept. of Mechanical and Civil Engineering, California Institute of Technology
³Professor, Dept. of Mechanical and Civil Engineering, California Institute of Technology

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Filtering removes parts of the signal that may be important in non-linear dynamic analysis of buildings.

Buyco et al. 2018
Tilt

Horizontal seismometers are sensitive to tilt.

\[ A_x(t) = \ddot{u}_x(t) + g \cdot \sin \theta_x(t) \approx \ddot{u}_x(t) + g \cdot \theta_x(t) \]

\[ \theta_x(t) = \dot{\theta}_x H(t - t_0) \]
Tilt

1999 M7.6 Chi-Chi - TCU084 (EW)

velocity (cm/s)

ramp

step

amplitude (sec)

amplitude

time (sec)
High-pass filtering

Long-period noise in raw records result in unrealistic trends in the velocity and displacement time series.

To remove noise, high-pass filters are applied.
High-pass filtering

- 2016 M7.0 Kumamoto - 93048 (EW)
- raw
- tilt corrected
- acausal
- causal

* filters are 30 sec high-pass *

- static offset ~1.75 m
- tilt ~0.08 degrees

- phase shift
- precursor
Data collection

23 stations
2016 M7.8 Kaikoura, New Zealand
2016 M7.0 Kumamoto, Japan
2015 M7.8 Gorkha, Nepal
1999 M7.6 Chi-Chi, Taiwan
1992 M7.3 Landers, California
2002 M7.9 Denali, Alaska
Methods
Method I
Tilt correction

1. Remove the pre-event mean from the data.
2. Integrate for velocity, and pick $t_0$ by inspection.
4. Integrate for displacement.
5. Compare with geodetic data (if available).
6. Iterate for displacement.
7. Iterate with different $t_0$ picks until displacement is stable or matches geodetic data.
8. Take two time derivatives for “tilt corrected” acceleration record.
Method II

Filtering

1. Take “tilt corrected” record from Method I.
2. Zero-pad beginning of the record.
3. Integrate twice to obtain displacement.
4. Apply acausal 4\textsuperscript{th}-order high-pass Butterworth filter at different corner periods.
## Results and analysis

### Tilt

<table>
<thead>
<tr>
<th></th>
<th>Tilt (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>median</td>
<td>0.0114 +/- 0.7533</td>
</tr>
<tr>
<td>maximum</td>
<td>2.732</td>
</tr>
<tr>
<td>minimum</td>
<td>2.745e-4</td>
</tr>
</tbody>
</table>

![Histogram of Tilt Values](image)
Results and analysis

Time series
Concluding remarks

• Filtering removes the additional acceleration that results from changes in the ground tilt, but it **also** removes parts of the signal that may be important in **nonlinear dynamic analysis** of tall, near-fault buildings.

• Tilt correction requires nonlinear operator and subjective judgment, but it represents data closest to the “true” ground acceleration.

• Tilt values, what the filters are removing, are small in comparison to peak acceleration of the actual ground motion.

• It is difficult to determine how much data to remove and still calculate an accurate building response.

• **There is no disadvantage in using tilt corrected records, or raw records, when evaluating building response.**
Thank you.

For questions and comments, contact:
Becky Roh | broh@caltech.edu