Near-Fault Velocity-Pulse Motions

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ATC-82
Near-Fault Ground Shaking
Forward-Directivity (NS) & Fling-Step (EW)

1999 Kocaeli, Turkey EQ (YPT Station)
FD Time-Domain Characterization through a velocity-time history (Bray & Rodriguez-Marek 2004)

- Pulse Amplitude
- PGV
- Pulse Period $T_v$
- Number of Cycles $N_c$

$N_c = 1$ (# > 0.5 PGV)

Pacoima Dam Downstream, 1994 Northridge EQ
Forward-Directivity FN & FP Velocity Pulses

Newhall-Pico Canyon

Rinaldi Receiving Station

1994 Northridge EQ
FD Site Effects

1989 Loma Prieta Earthquake

- Gilroy #1: Rock
  - $T_v = 1.2 \, \text{s}; \, PGV = 39 \, \text{cm/s}$

- Gilroy Gavilan College: Rock
  - $T_v = 1.2 \, \text{s}; \, PGV = 31 \, \text{cm/s}$

- Gilroy #2: Soil
  - $T_v = 1.4 \, \text{s}; \, PGV = 46 \, \text{cm/s}$

- Gilroy #3: Soil
  - $T_v = 1.5 \, \text{s}; \, PGV = 49 \, \text{cm/s}$
FD Motions Site-Dependent Estimates

Bray et al. 2009  (68 FD Motions)

Peak Ground Velocity

\[ \ln(\text{PGV}_{ij}) = a + b M_w + c \ln (R^2 + d^2) + \epsilon \]

Pulse Period

\[ \ln(T_v)_{ij} = a + b M_w + \epsilon \]

Number of Cycles

\[ N_e \sim 1 \text{ or } 2 \]
Near-Fault Pulse Motions

Baker 2007 (91 FN Pulse Motions); Shahi & Baker 2011 (179 Max. Comp. Pulse Motions)
Near-Fault Pulse Motions (Shahi & Baker 2011)

Imperial Valley EQ: (a) contours of probability of pulse occurrence for rupture, & (b) sites where pulse like ground motion was observed.
Near-Fault Pulse Motion Databases

68 Bray & Rodriguez-Marek and 179 Shahi & Baker motions - 48 common pulse motions

<table>
<thead>
<tr>
<th>Event</th>
<th>Station</th>
<th>Mw</th>
<th>B-RM PGV (cm/s)</th>
<th>S-B PGV (cm/s)</th>
<th>B-RM Tv (s)</th>
<th>S-B Tv (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imperial Valley 1979</td>
<td>Brawley Airport</td>
<td>6.5</td>
<td>36.1</td>
<td>36.1</td>
<td>2.56</td>
<td>4.0</td>
</tr>
<tr>
<td>Landers 1992</td>
<td>Lucerne</td>
<td>7.3</td>
<td>147</td>
<td>140</td>
<td>5.39</td>
<td>5.1</td>
</tr>
<tr>
<td>Northridge 1994</td>
<td>Pacoima Dam (upper left)</td>
<td>6.7</td>
<td>107</td>
<td>107</td>
<td>0.89</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Notes: 1. B-RM used FN comp. & S-B used max. comp. (was 91 FN)
2. B-RM used FN/FP $S_a(3s)$ ratio and judgment, & S-B used algorithm to classify pulse motions
Classify Near-Fault Motions for New Database

- **Near-Fault Region (R ≤ 30 km):**

- Pulse motions

- “Ordinary” non-pulse motions
Pulse Motions Intensity Measure

max. PGV vs. max. Peak-to-Peak Velocity

PGV = 39 cm/sec

PPV = 60 cm/sec

Imperial Valley 1979, Brawley Airport, USGS = Site C, R = 8.5 km, Fault Strike = 323 degrees
Pulse Motion Orientation

Max. Component: 255 vs. Fault-Normal: 233

Min. Component: 315 vs. Fault-Parallel: 323

Imperial Valley 1979, Brawley Airport, USGS = Site C, R = 8.5 km, Fault Strike = 323 degrees
Processing of Pulse Motions

325 motions from NGA database with $M_w \geq 6.0$ & $R \leq 30$ km

Rotate to find max. component PGV

Estimate $T_v$ at peak ratio of spectral velocities of maximum and median estimate components
Processing & Classifying Pulse Motions

Earthquake: Chi-Chi, Taiwan  Station: TCU068  ID#: 1505  Frequency cutoff: 0.5Hz
Score: 100  B-RM: 1  S-B: 1  Cutoff Override: 0

Original Vel.-time Hist. – Max. Comp.

Filtered Vel.-time Hist.
low-pass 3-pole causal
Butterworth set at 3 x (1/\(T_v\))


PPV
Classifying Pulse Motions

Identify key features of a pulse motion
Classifying Pulse Motions

Pulse Motion (Score=100):
Imperial Valley 1979
El Centro Array #7
USGS = Site C, R = 0.6 km

Non-Pulse Motion (Score = 40):
Loma Prieta 1989
Hollister City Hall
USGS = Site C, R = 27.6 km
Classifying Pulse Motions

88 Pulse Motions Classified: (97 → 88)
54 FD pulse motions (e.g., high IDP & PGV ratio)
34 non-FD pulse motions
Estimate # of Pulse Motions

Contours of proportion of pulse motions as a function of $R \& \varepsilon$
Model to Estimate # of Pulse Motions

Proportion of Pulse Motions = \frac{\exp(0.905 - 0.188 \times R + 1.337 \times \varepsilon)}{1 + \exp(0.905 - 0.188 \times R + 1.337 \times \varepsilon)}

\begin{align*}
R = 10 \text{ km} & \quad & \varepsilon = 1 & \quad & 60\% \text{ pulse} \\
& \quad & \text{4 of 7 motions} \\
R = 20 \text{ km} & \quad & \varepsilon = 0.5 & \quad & 10\% \text{ pulse} \\
& \quad & \text{1 of 7 motions}
\end{align*}
Proportion of pulse motions depends on PGV epsilon (ε) & Distance (R)
Selection of Pulse Motions

- Consider conventional issues such as R, $M_w$, & Site

- PSHA defines $S_a$ at period of structure. Also, PGV and $T_v$ can be estimated using existing empirical relations (e.g., Bray et al. 2009)

- Select FD pulse motion based on period range of interest of structure
  - [Motion from lower $M_w$ EQ with a lower PGV may be more damaging if its pulse period is aligned with structure period]

- FD pulse motions provided in two period ranges:
  - $T = 0.7$ s to $2.2$ s - 34 pulse records
  - $T = 2.2$ s to $6$ s - 54 pulse records
Max PPV component of FD pulse motions tends to be oriented +/- 30° of FN.

No preferred orientation for non-FD pulse motions & No clear trend with R.
CONCLUSIONS

Near-fault pulse motion database developed that serves an alternative to existing B-RM and S-B pulse motions

- Estimate proportion of pulse motions based on epsilon of design value ($S_a(T_n)$ or PGV) and distance

- Select pulse motions based on $T_n$ of structure, and scale to have specified $S_a(T_n)$ or PGV with pulse preserved

- Max component is likely oriented within 30° of FN direction