USE OF $V_{s30}$ TO REPRESENT LOCAL SITE CONDITIONS

Presented by

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The $V_{s30}$ Dialog
How We Can & Cannot use $V_{s30}$ in Site Response Estimation?

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Effects OF Surface Geology on Strong Ground Motion
Santa Barbara, California
August 26, 2011
Wave propagation theory suggests that ground motion amplitude should depend on the density and shear wave velocity, $V_s$, of the near surface material (e.g., Bullen, 1965; Aki & Richards, 1980). Density does not vary very much with depth; hence $V_s$ becomes the logical choice for representing site conditions.

The essential issue then becomes in how to express this dependence.
Two methods have been proposed over the past 30 years.
Method No. 1

1. The "average" velocity over the depth range corresponding to \( \frac{1}{4} \) wavelength of the period of interest (Joyner et al, 1981).
Frequency (Hz)

1/4 Wave Length (m)

Average Vs = 1100 m/s
Average Vs = 800 m/s
Average Vs = 400 m/s
Average Vs = 200 m/s
Method No. 2

2. The use of $V_{s30}$ (Borcherdt, 1994), who recommended the use of $V_{s30}$ as a means for classifying Site Categories for building codes.
\[
f_5\left(\text{PGA}_{1100}, V_{S30}^*\right) = a_{10} \ln\left(\frac{V_{S30}^*}{V_{LIN}}\right) - b \ln(\text{PGA}_{1100} + c) + b \ln\left[\text{PGA}_{1100} + c \ln\left(\frac{V_{S30}^*}{V_{LIN}}\right)^n\right]
\]

for \(V_{S30} < V_{LIN}\)

\[
f_5\left(\text{PGA}_{1100}, V_{S30}^*\right) = (a_{10} + bn) \ln\left(\frac{V_{S30}^*}{V_{LIN}}\right)
\]

for \(V_{S30} \geq V_{LIN}\)

\[
V_{S30}^* = V_{S30} \quad \text{for} \quad V_{S30} < V_1
\]

\[
V_{S30}^* = V_1 \quad \text{for} \quad V_{S30} \geq V_1
\]

\[
V_1 = 1500 \text{ m/s} \quad \text{for} \quad T \leq 0.50 \text{ sec}
\]

\[
V_1 = \exp\left[8.0 - 0.795 \ln\left(\frac{T}{0.21}\right)\right] \quad \text{for} \quad 0.50 \text{ sec} < T \leq 1 \text{ sec}
\]

\[
V_1 = \exp\left[6.76 - 0.297 \ln(T)\right] \quad \text{for} \quad 1 \text{ sec} < T < 2 \text{ sec}
\]

\[
V_1 = 700 \text{ m/s} \quad \text{for} \quad T \geq 2 \text{ sec}
\]
More recently, four of the five NGA relationships used $V_{s30}$ as an independent parameter to explicitly represent local site conditions.

Example of the $V_{s30}$ scaling for $T = 0.2$ sec
From Abrahamson & Silva (2008)
Shear wave velocity, $V_{s30}$ (m/s)

PGA for $V_{s30}$ = 1100 m/s

PGA
- Abrahamson & Silva (2008)
- Campbell & Bozorgnia (2008)
- Chiou & Youngs (2008)

Average
Shear wave velocity, $V_{s30}$ (m/s)

PSA for $V_{s30}$ / PSA for $V_{s30} = 1100$ m/s

Abrahamson & Silva (2008)
Campbell & Bozorgnia (2008)
Chiou & Youngs (2008)

PSA for $T = 1$ sec

Average

Shear wave velocity, $V_{s30}$ (m/s)
NGA DATA
2011 FLATFILE
Closest distance, $R$ (km)

Earthquake magnitude, $M$

From Flatfile
Earthquake magnitude, $M$ vs. $V_{s30}$ (m/s)
From Flatfile

- Best estimate for $R \leq 160$ km
- Best estimate for $R > 160$ km

**Tottori; $M = 6.6$; Mech 0**
- Dist, $R \leq 160$ km
- Dist, $R > 160$ km

PGA values adjusted to $V_{s30} = 580$ m/s
<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-FF</td>
<td>426</td>
</tr>
<tr>
<td>Mag not listed</td>
<td>201</td>
</tr>
<tr>
<td>Mechanism not listed</td>
<td>139</td>
</tr>
<tr>
<td>Distance not listed</td>
<td>92</td>
</tr>
<tr>
<td>Vs30 not listed</td>
<td>17</td>
</tr>
<tr>
<td>PSA not listed</td>
<td>63</td>
</tr>
<tr>
<td>Mag &lt; 4.5</td>
<td>173</td>
</tr>
<tr>
<td>Distance &gt; 160 km</td>
<td>1890</td>
</tr>
<tr>
<td>Others</td>
<td>136</td>
</tr>
</tbody>
</table>

Total No. of FF Entries to be used 5026
FF Records; Dist ≤ 160 km; M ≥ 4.5
**FF Records; Dist ≤ 160 km; M ≥ 4.5**

- Earthquake magnitude, $M$
- $V_{s30}$ (m/s)
FF Records; Dist ≤ 160 km; M ≥ 4.5
FF Records; Dist $\leq 160$ km; $M \geq 4.5$
DATA SET

Stations having \( V_{s30} \geq 450 \text{ m/s} \) and \( R \leq 160 \text{ km} \)

Total Number of records used = 1288
[147 recordings (\( V_{s30} \geq 450 \text{ m/s} \)) from the Chi-Chi main shock were excluded]

\[ 4.5 \leq M \leq 7.9 \]

\[ 0.9 \text{ km} \leq R \leq 160 \text{ km} \]

\[ 450 \text{ m/s} \leq V_{s30} \leq 2016 \text{ m/s} \]
[only 10 recordings at site with \( V_{s30} > 1200 \text{ m/s} \)]
\[ \ln(y) = (a_1 + a_2 M) - (b_1 + b_2 M) \ln(R + 10) + g R + \alpha \left( V_{s30} - 450 \right) + f \]
Earthquake magnitude, $M$

Residual

Discrete averages over $M$, $R$, or $V_{s30}$ bins

Individual recording

Overall trend
Residual vs $V_{s30} (m/s)$
Closest distance, $R$ (km)

PGA (g)

<table>
<thead>
<tr>
<th>$M$</th>
<th>$V_{s30}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5</td>
<td>450 m/s</td>
</tr>
<tr>
<td>7.5</td>
<td>900 m/s</td>
</tr>
</tbody>
</table>

2008 relationship

$V_{s30} = 450$ m/s

$V_{s30} = 900$ m/s

2011 relationship

$V_{s30} = 450$ m/s

$V_{s30} = 900$ m/s
Shear wave velocity, $V_{s30}$ (m/s)

PGA for $V_{s30} = 1100$ m/s

Based on IMI_2011

**PGA**
- ● Abrahamson & Silva (2008)
- ▲ Campbell & Bozorgnia (2008)
- ● Chiou & Youngs (2008)
- ▲ Average

Shear wave velocity, $V_{s30}$ (m/s)
Shear wave velocity, $V_{s30}$ (m/s)

PSA for $V_{s30} = 1100$ m/s

Based on IMI_2011
WHAT DO THE NGA DATA SHOW?
Examination in terms of the ratio of:

$$\frac{PGV}{V_{s30}}$$

which may be considered as a "proxy" for shear strain induced by the earthquake ground motions

Plotting PGA versus this ratio can then be examined as if it were a "stress-strain" relationship
$V_{s30}$ based on measured $V_s$

Range & number of $V_{s30}$ values:
- 800 to 900 m/s; 29
- 900 to 1000 m/s; 12
- 1000 to 1200 m/s; 16
- 1200 to 1400 m/s; 8
- 1500 to 2000 m/s; 4
Shear strain (%)

PGA (g)

$V_{s30}$ based on measured $V_s$

Range & number of $V_{s30}$ values
- ▲ 450 to 500 m/s; 129
- ▲ 500 to 550 m/s; 151
- ▲ 550 to 600 m/s; 89
- ▲ 600 to 700 m/s; 64
- ▲ 700 to 800 m/s; 131

480 recordings
Shear strain (%)

PGA (g)

Range & number of $V_{s30}$ values
- $450$ to $500$ m/s; $129$
- $500$ to $550$ m/s; $151$
- $550$ to $600$ m/s; $89$
- $600$ to $700$ m/s; $64$
- $700$ to $800$ m/s; $131$

$V_{s30}$ based on measured $V_s$

22 recordings
47 recordings
16 recordings

Shear strain (%)
Shear strain (%)

G/G\textsubscript{max}

Clay; PI = 30
Weathered rock
Comp rock

\textbf{Comp rock}
\textbf{Weathered rock}
\textbf{Clay; PI = 30}

Shear strain (%)
Shear strain (%)

PGA (g)

Range & number of $V_{s30}$ values
- 225 to 250 m/s; 101
- 250 to 300 m/s; 186
- 300 to 350 m/s; 170
- 350 to 400 m/s; 144
- 400 to 450 m/s; 131

$V_{s30}$ based on measured $V_s$
Shear strain (%)

G/G_{max}

Sand layers over depth range of:
- ≤ 20 ft
- 20 to 50 ft
- 50 to 120 ft
- 120 to 250 ft
- ≥ 500 ft
Shear strain (%)

PGA (g)

Range & number of $V_{s30}$ values
- 100 to 140 m/s; 10
- 140 to 180 m/s; 27
- 180 to 200 m/s; 132
- 200 to 210 m/s; 74

$V_{s30}$ based on measured $V_s$
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Engineering and Soil Dynamics

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Vol. III

St. Louis, MO 1991

Editor: Shamsher Prakash

University of Missouri-Rolla
Rolla, Missouri
Examination in terms of:

Variations of PGA and PSA, at $T = 1$ sec, with Distance

For various bins of $V_{s30}$

Chi-Chi main shock data
Peak horizontal acceleration (g)

Closest distance to rupture surface (km)

Chi Chi main shock
$M = 7.6$; Mechanism 3

$p_{ga}$

$V_{30}$ (m/s) =
- 440 - 450
- 420 - 440
- 400 - 420
- 380 - 400
- 360 - 380
- 340 - 360
- 320 - 340
- 300 - 320
- 280 - 300
- 260 - 280
- 240 - 260
- 220 - 240
- 200 - 220
- 180 - 200
Regression curve for

- $V_{s30} (m/s) = 420 - 440$
- $V_{s30} (m/s) = 400 - 420$
- $V_{s30} (m/s) = 220 - 240$
- $V_{s30} (m/s) = 200 - 220$

Chi Chi main shock
$M = 7.6$; Mechanism 3

Peak horizontal acceleration (g)

Closest distance to rupture surface (km)
PGA calculated at a Distance = 3 km, Distance = 30 km, Distance = 100 km.
Based on Chi-Chi Recordings

PSA ($T = 1$ s) for $V_{s30} = 450$ m/s
Based on recorded data from other than the Chi-Chi earthquake
Range of $V_{s30}$

**Landers earthquake, $M = 7.28$**
- Δ 400 to 450 m/s (10)
- ▲ 350 to 400 m/s (8)
- △ 300 to 350 m/s (34)
- ○ 250 to 300 m/s (13)
- △ 200 to 250 m/s (5)

**Sierra el Mayor earthquake, $M = 7.2$**
- ● 400 to 450 m/s (27)
- ▲ 350 to 400 m/s (32)
- △ 300 to 350 m/s (46)
- ○ 250 to 300 m/s (56)
- △ 200 to 250 m/s (22)

**Hector Mine earthquake, $M = 7.13$**
- ● 400 to 450 m/s (5)
- ▲ 350 to 400 m/s (34)
- △ 300 to 350 m/s (32)
- ○ 250 to 300 m/s (33)
- △ 200 to 250 m/s (6)
Recorded values at sites with range of $V_{s30} = 400$ to 450 m/s

- Landers earthquake, $M = 7.28$
- Sierra el Mayor earthquake, $M = 7.2$
- Hector Mine earthquake, $M = 7.13$
Recorded values at sites with range of $V_{s30} = 350$ to $400$ m/s

- Landers earthquake, $M = 7.28$
- Sierra el Mayor earthquake, $M = 7.2$
- Hector Mine earthquake, $M = 7.13$
Regressed curve

Recorded values at sites with range of $V_{s30}$ = 300 to 350 m/s

Landers earthquake, $M = 7.28$
Sierra el Mayor earthquake, $M = 7.2$
Hector Mine earthquake, $M = 7.13$
Recorded values at sites with range of $V_{s30} = 250\text{ to } 300 \text{ m/s}$

Regression curve

Landers earthquake, $M = 7.28$
Sierra el Mayor earthquake, $M = 7.2$
Hector Mine earthquake, $M = 7.13$
Recorded values at sites with range of $V_{s30} = 200$ to $250$ m/s
Regressed curve

- Landers earthquake, $M = 7.28$
- Sierra el Mayor earthquake, $M = 7.2$
- Hector Mine earthquake, $M = 7.13$
PGA (g)

Range of $V_{s30} = 400$ to $450$ m/s

Range of $V_{s30} = 350$ to $400$ m/s

Range of $V_{s30} = 300$ to $350$ m/s

Range of $V_{s30} = 250$ to $300$ m/s

Range of $V_{s30} = 200$ to $250$ m/s

Landers earthquake, $M = 7.28$
Sierra el Mayor earthquake, $M = 7.2$
Hector Mine earthquake, $M = 7.13$

Closest distance (km)
Recorded values at sites with range of \( V_{s30} = 300 \) to 350 m/s

Regressed curve

Loma Prieta earthquake, \( M = 6.9 \)
Iwate earthquake, \( M = 6.9 \)
Chuetsu-Oki earthquake, \( M = 6.8 \)
Kobe earthquake, \( M = 6.9 \)
Closest distance (km)

Loma Prieta earthquake, $M = 6.9$
Iwate earthquake, $M = 6.9$
Chuetsu-Oki earthquake, $M = 6.8$
Kobe earthquake, $M = 6.9$

PGA (g)

Regressed curves
- Range of $V_{s30}$ = 400 to 450 m/s
- Range of $V_{s30}$ = 350 to 400 m/s
- Range of $V_{s30}$ = 300 to 350 m/s
- Range of $V_{s30}$ = 250 to 300 m/s
- Range of $V_{s30}$ = 200 to 250 m/s
WHAT DO THE NGA DATA SHOW?

The data generally do not fully support the "published" trends.
Site Response Studies
Depth below ground surface (m)

- Layer 1
- Layer 2
- Layer 3
- Layer 4
- Layer 5
- Layer 6

Halfspace
$V_s = 1100 \text{ m/s}$

Shear wave velocity, $V_s$ (m)

Profile abc
$V_{s30} = 220 \text{ m/s}$
Profile cba
\[ V_{s30} = 220 \text{ m/s} \]
CONCLUDING REMARKS

✓ $V_{s30}$ is not a fundamental geotechnical parameter

✓ $V_{s30}$ is not a unique geotechnical parameter

✓ Since $G/G_{\text{max}}$ is material-dependent

✓ $V_{s30}$ is neither necessary nor sufficient to describe or accommodate nonlinear effects
CONCLUDING REMARKS

- The contributions of the soil profile below 30 m to site response, cannot be accommodated with the use of $V_{s30}$ with or without including the depth to $V_s = 1 \text{ km/s}$ or to $V_s = 2.5 \text{ km/s}$ (even if these depths are known for a sufficient number of sites).

- Sites with "identical" $V_{s30}$, but differing layering, can have significantly different response
CONCLUDING REMARKS

- Additional work is needed before $V_{s30}$ should be used as a continuous independent parameter in earthquake ground motions attenuation relationships.

- The use of a range of $V_{s30}$ to describe a generalized "site category" for building code purposes, is reasonable.
CONCLUDING REMARKS

✓ Site-specific response calculations (with at least 7 rock outcrop input motions) are preferable for assessing local site effects – this requires high quality site response calculations.

✓ Distance dependence can be critical – further studies are in progress, incorporating V_{s30} in estimating the slope of the attenuation relationship.
STAY TUNED
THANK  YOU