USE OF V_{S30} TO REPRESENT LOCAL SITE CONDITIONS

Presented by

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Presented at the Session 6 on

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

4th IASPEI / IAEE International Symposium
Effects OF Surface Geology on Strong Ground Motion
Santa Barbara, California
August 26, 2011

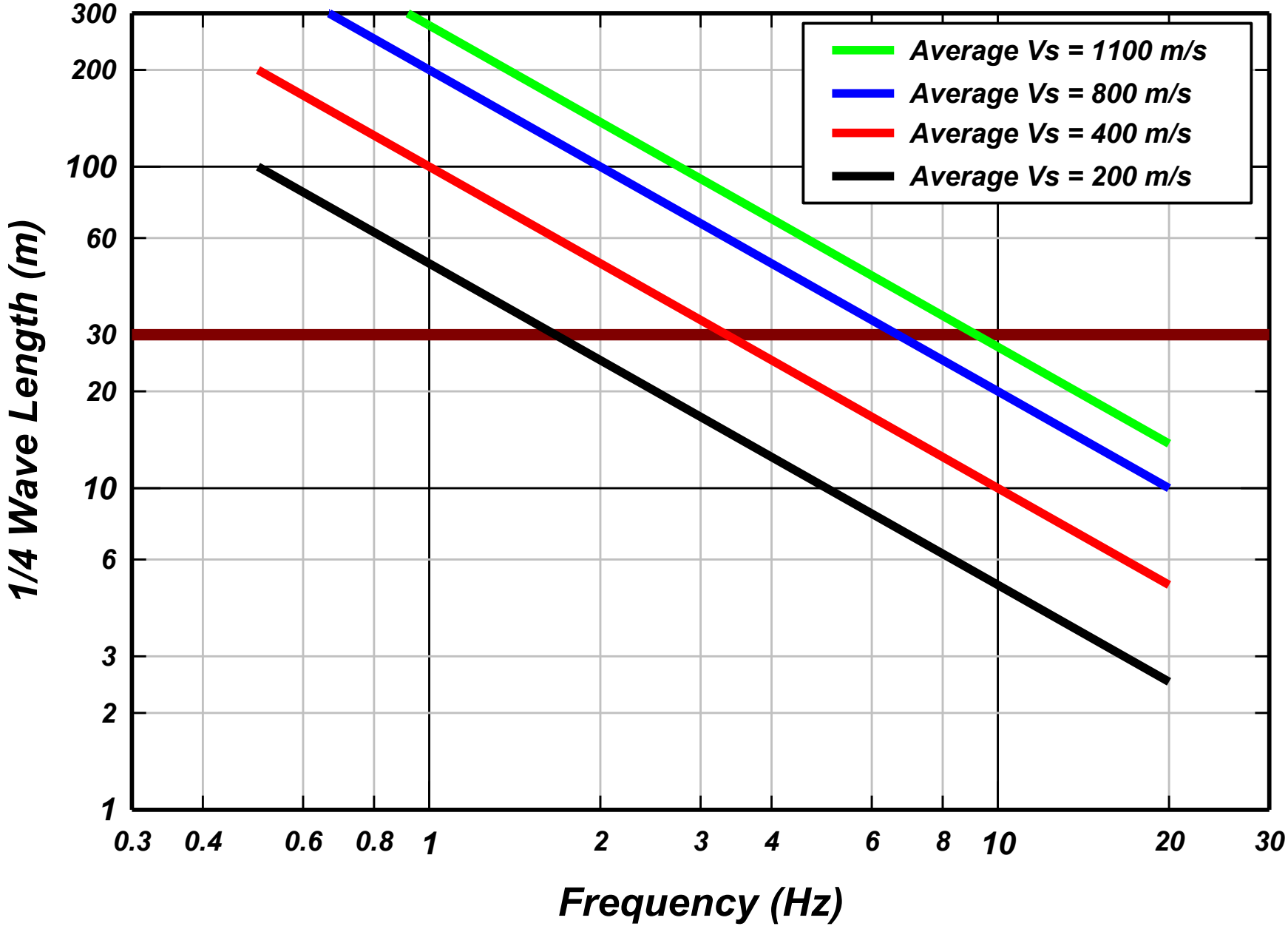
Wave propagation theory suggests that ground motion amplitude should depend on the density and shear wave velocity, V_s, of the near surface material (e.g., Bullen, 1965; Aki & Richards, 1980). Density does not vary very much with depth; hence V_s becomes the logical choice for representing site conditions.

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 ¼ wavelength of the period of interest (Joyner et al, 1981).***


Average Vs = 1100 m/s
Average Vs = 800 m/s
Average Vs = 400 m/s
Average Vs = 200 m/s
1/4 Wave Length (m)
300
200
100
60
30
20
10
6
3
2
1
0.3
0.4
0.6
0.8
1
2
3
4
6
8
10
20
30
Frequency (Hz)

Method No. 2

2. The use of V_{s30} (Borcherdt, 1994) , who recommended the use of Vs30 as a means for classifying Site Categories for building codes.

$$f_5\left(PGA_{1100}, V_{S30}^{*}\right) = a_{10}Ln\left(\frac{V_{S30}^{*}}{V_{LIN}}\right) - bLn\left(PGA_{1100} + c\right) + bLn\left[PGA_{1100} + cLn\left(\frac{V_{S30}^{*}}{V_{LIN}}\right)^{n}\right] \quad \text{for } V_{S30} < V_{LIN}$$

$$f_5\left(PGA_{1100}, V_{S30}^{*}\right) = \left(a_{10} + bn\right)Ln\left(\frac{V_{S30}^{*}}{V_{LIN}}\right) \quad \text{for } V_{S30} \geq V_{LIN}$$

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

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

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

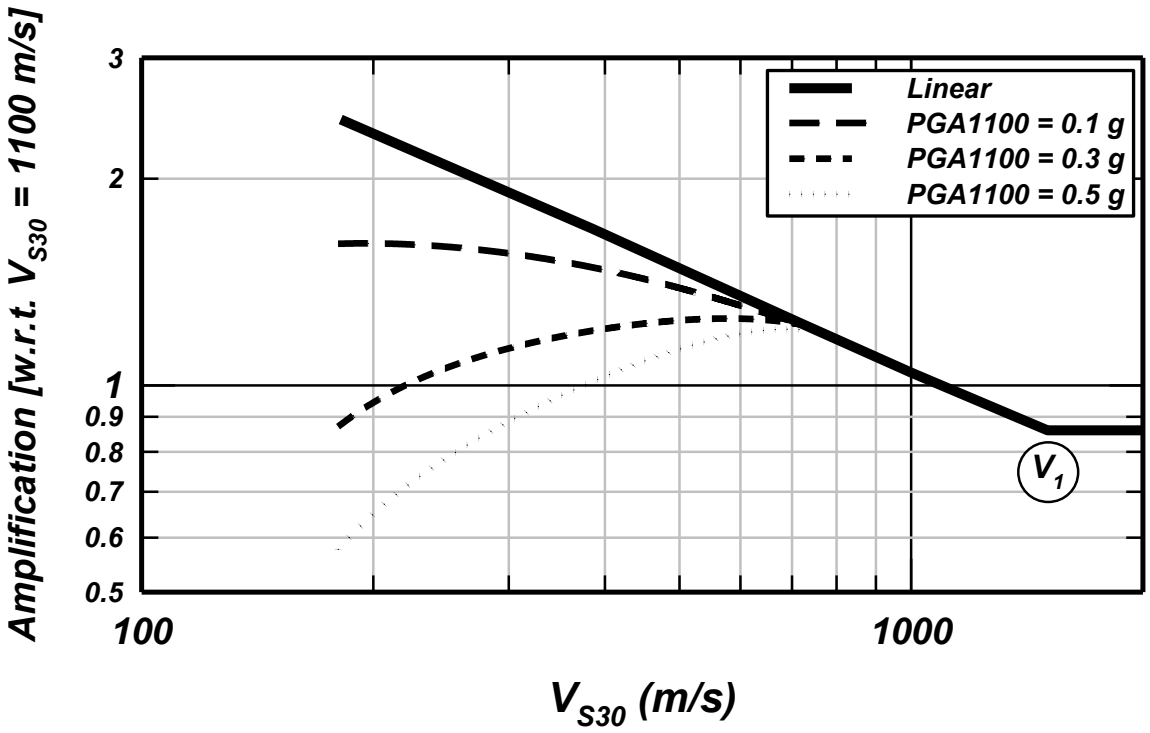
$$V_1 = \exp\left[8.0 - 0.795Ln\left(T/0.21\right)\right] \quad \text{for } 0.50 \text{ sec} < T \leq 1 \text{ sec}$$

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

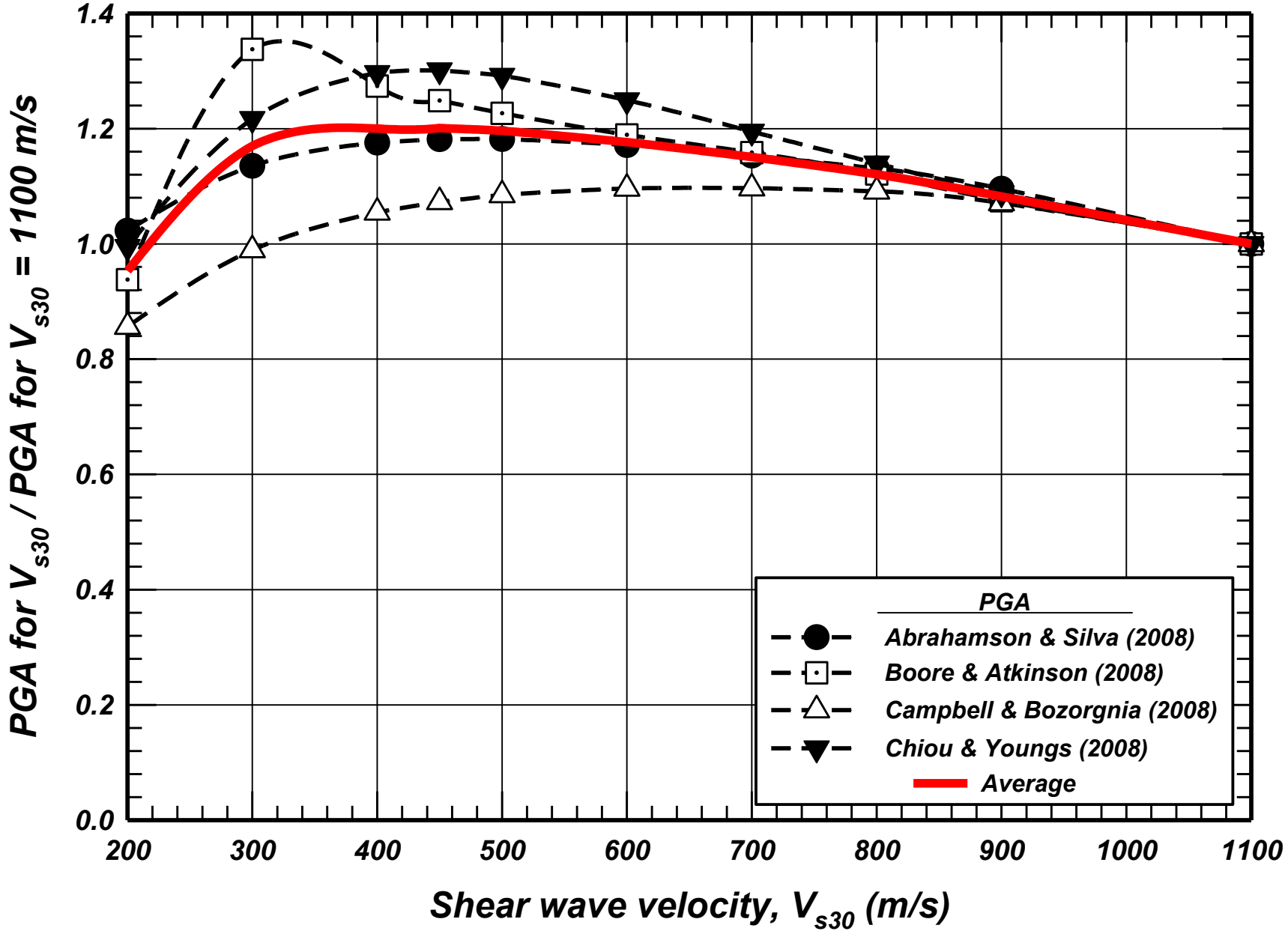
$$V_1 = 700 \text{ m/s} \quad \text{for } T \geq 2 \text{ sec}$$

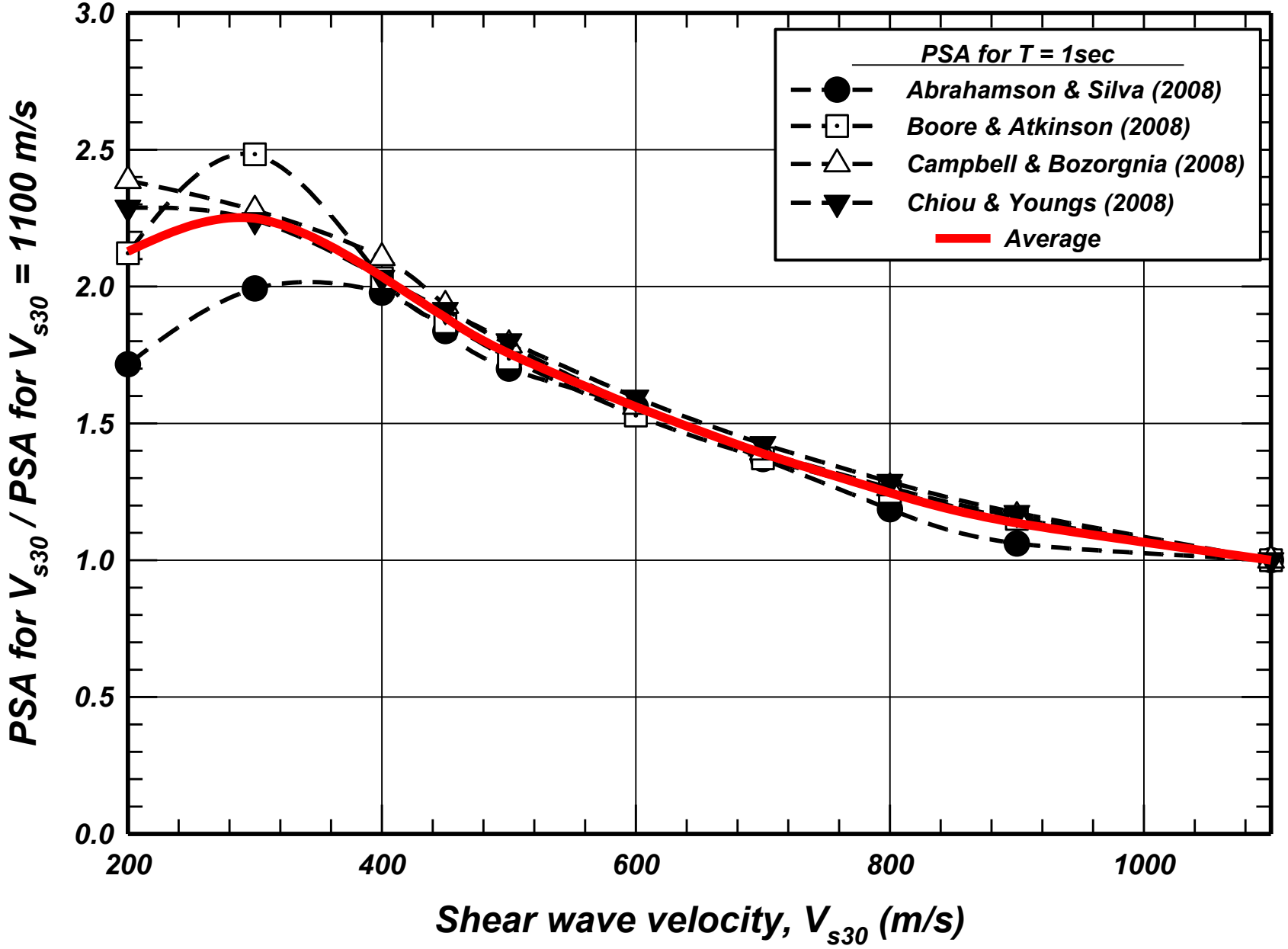
From Abrahamson & Silva (2008)

More recently, four of the five NGA relationships used V_{s30} as an independent parameter to <u>explicitly</u> represent local site conditions.



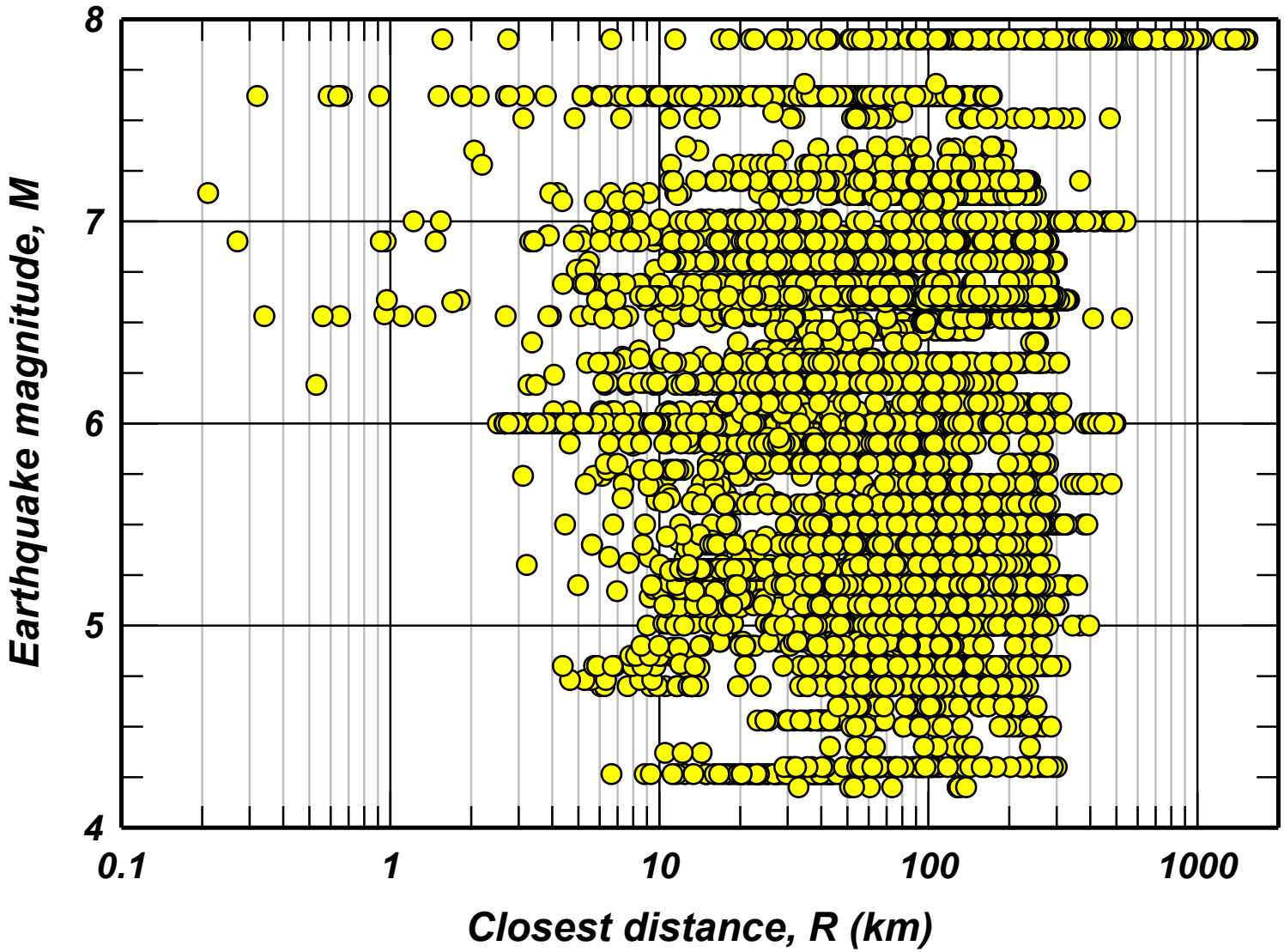
Example of the V_{S30} scaling for T = 0.2 sec
From Abrahamson & Silva (2008)


PGA for V_{s30} / PGA for V_{s30} = 1100 m/s
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
200
300
400
500
600
700
800
900
1000
1100
Shear wave velocity, V_{s30} (m/s)
PGA
Abrahamson & Silva (2008)
Boore & Atkinson (2008)
Campbell & Bozorgnia (2008)
Chiou & Youngs (2008)
Average

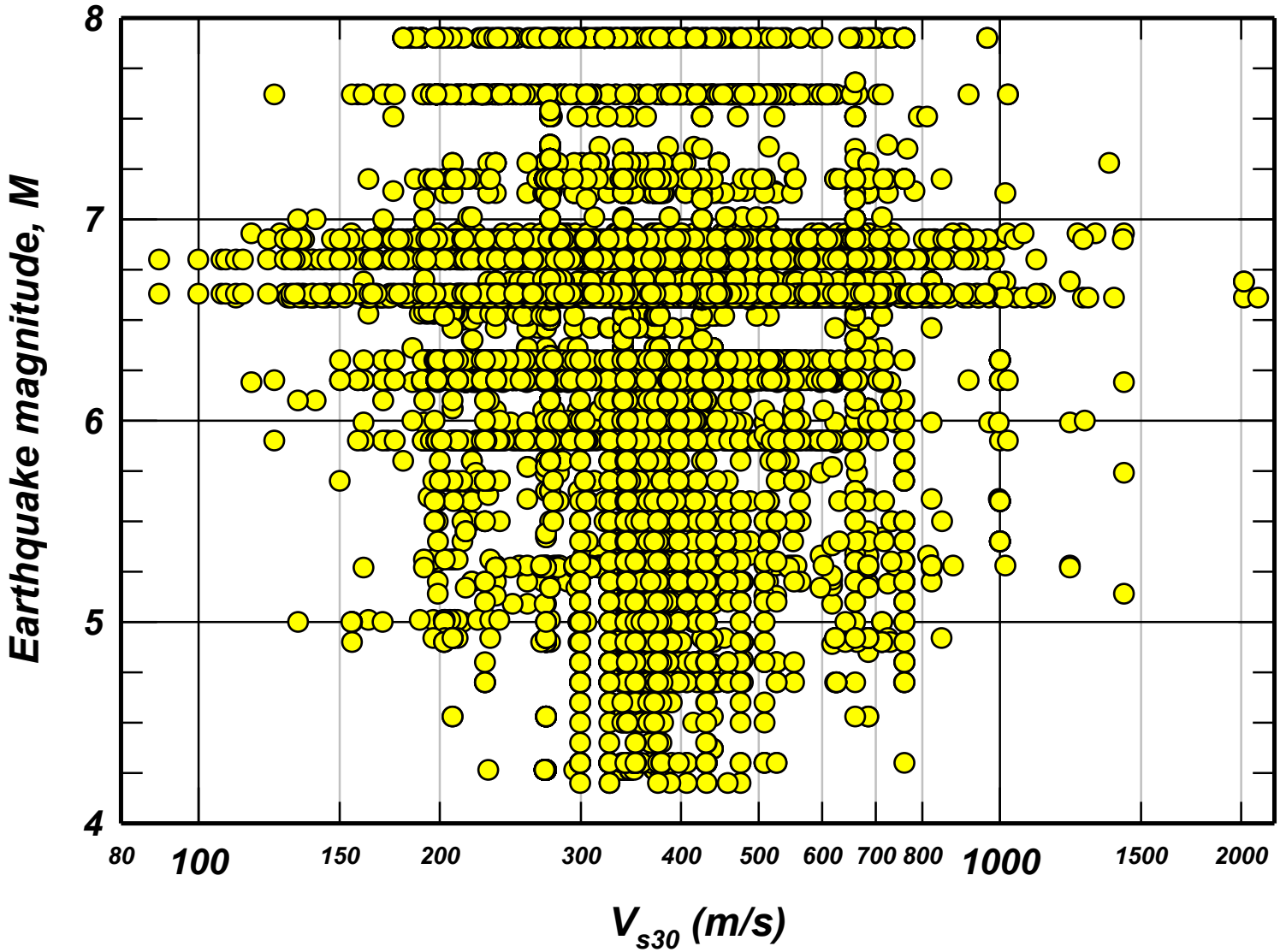

PSA for T = 1sec
Abrahamson & Silva (2008)
Boore & Atkinson (2008)
Campbell & Bozorgnia (2008)
Chiou & Youngs (2008)
Average
PSA for V_{s30} / PSA for V_{s30} = 1100 m/s
Shear wave velocity, V_{s30} (m/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200
400
600
800
1000

NGA DATA
2011 FLATFILE

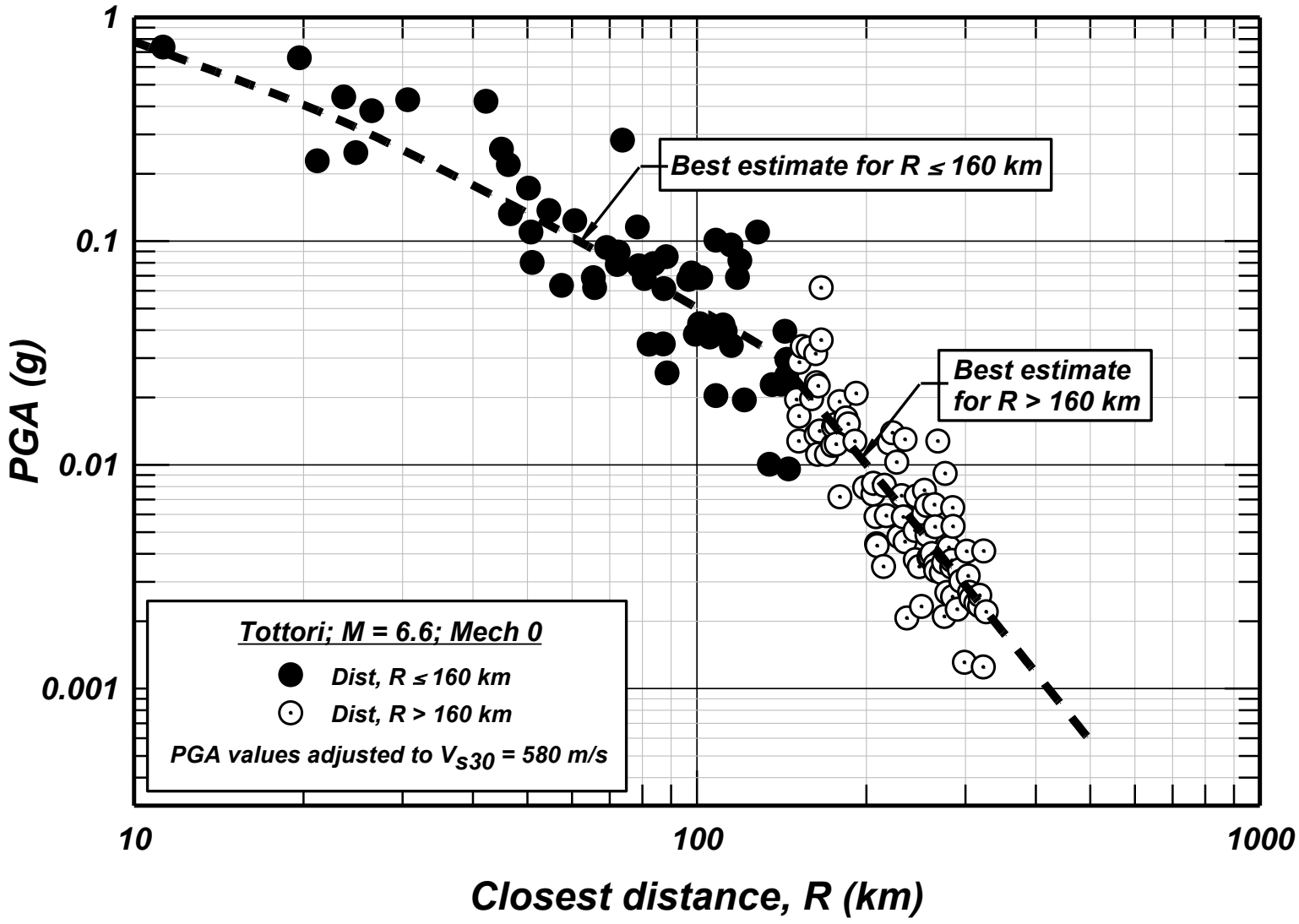
From Flatfile



From Flatfile



From Flatfile

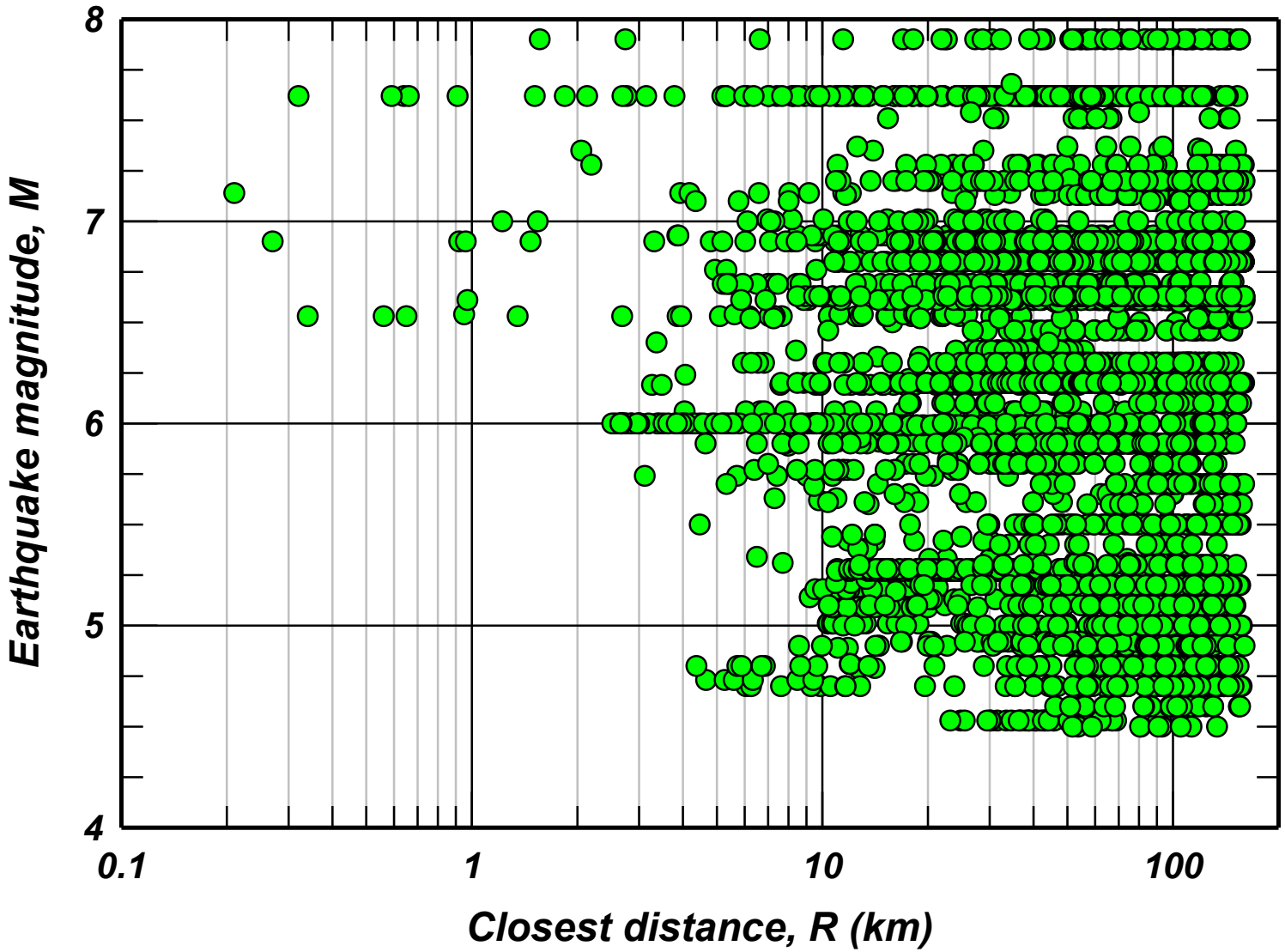


Total No. of Entries 8163

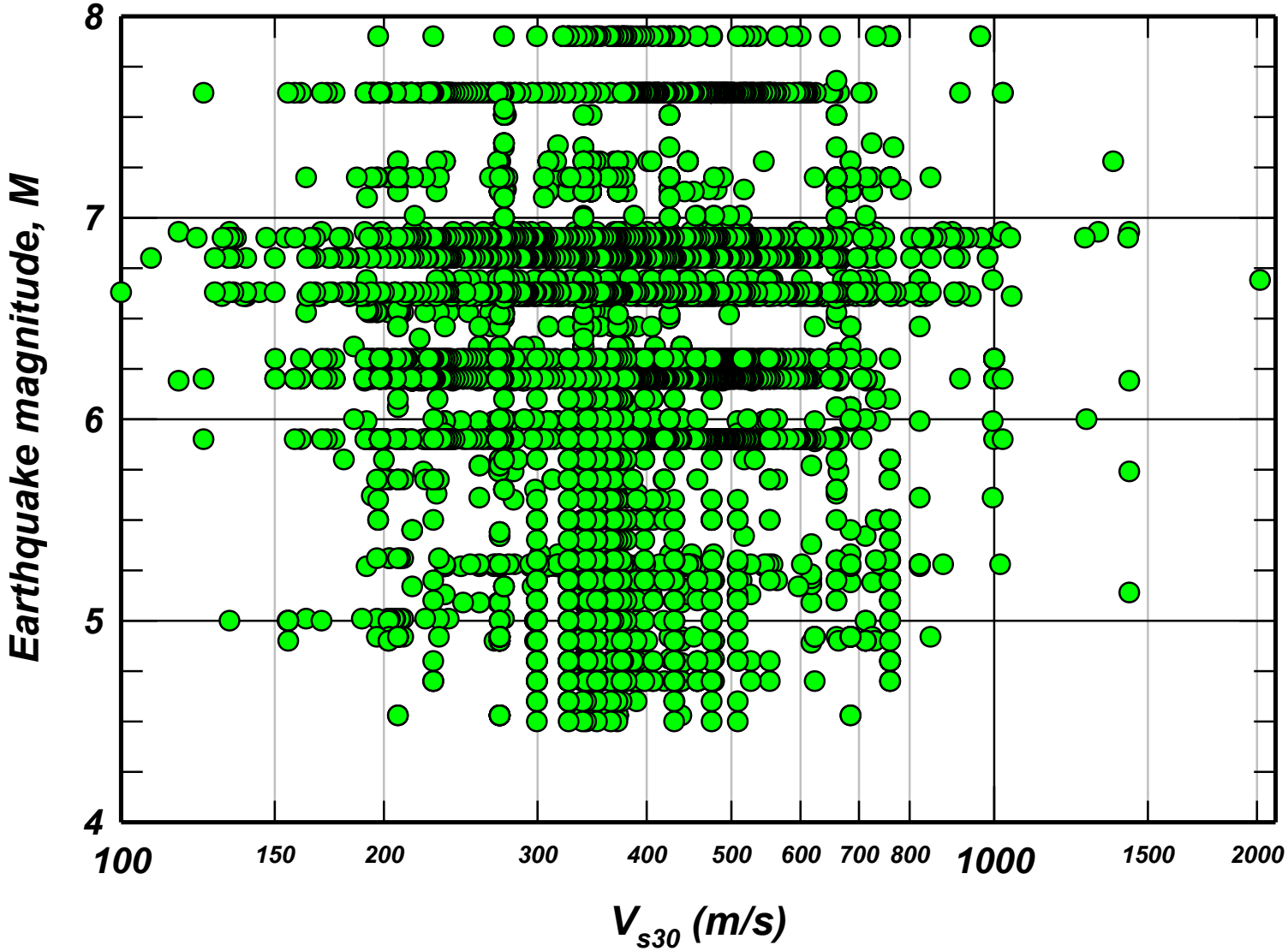
Non-FF	426
Mag not listed	201
Mechanism not listed	139
Distance not listed	92
Vs30 not listed	17
PSA not listed	63
Mag < 4.5	173
Distance > 160 km	1890
Others	136

Total No. of FF Entries to be used 5026

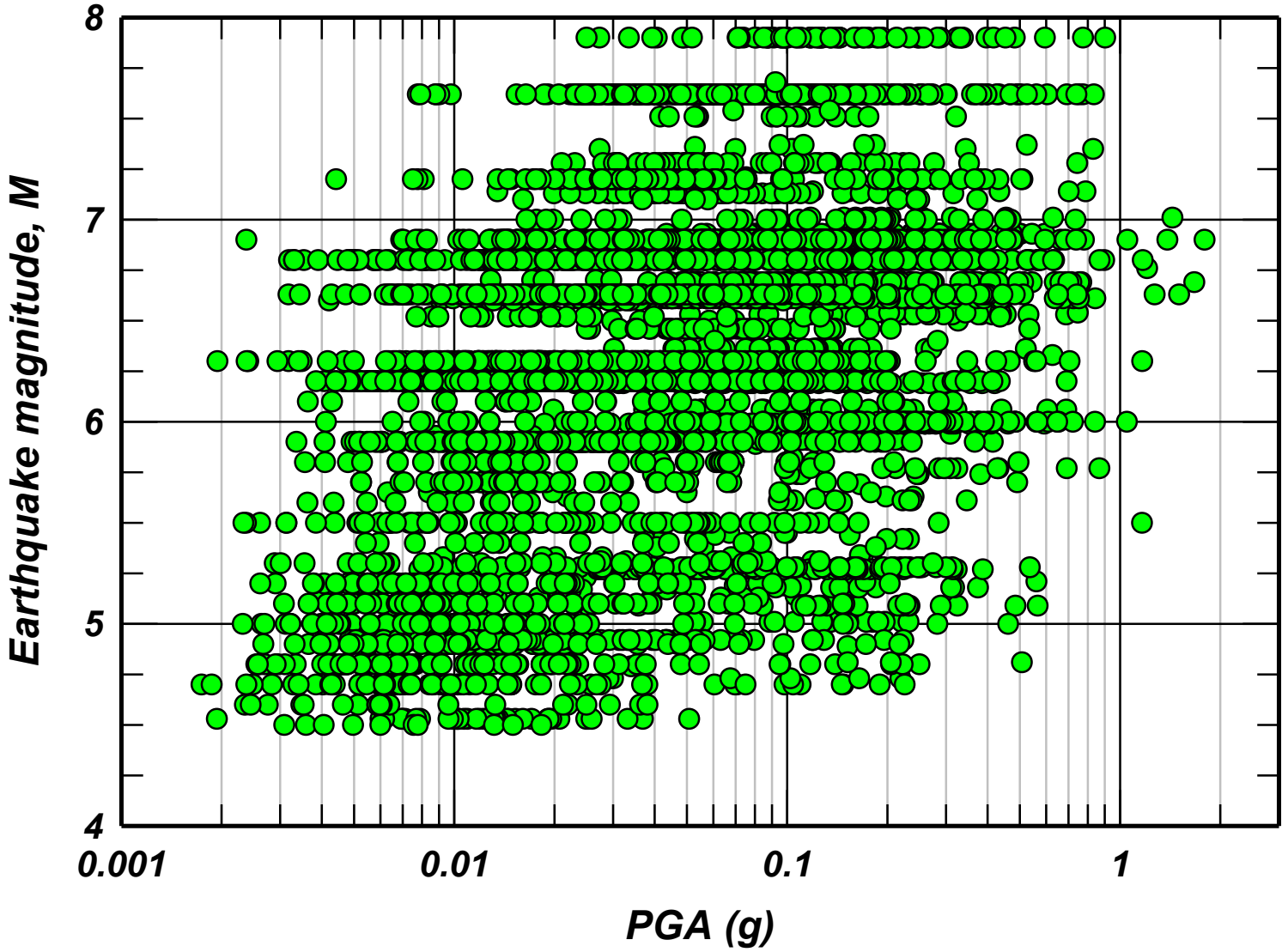
FF Records; Dist ≤ 160 km; M ≥ 4.5



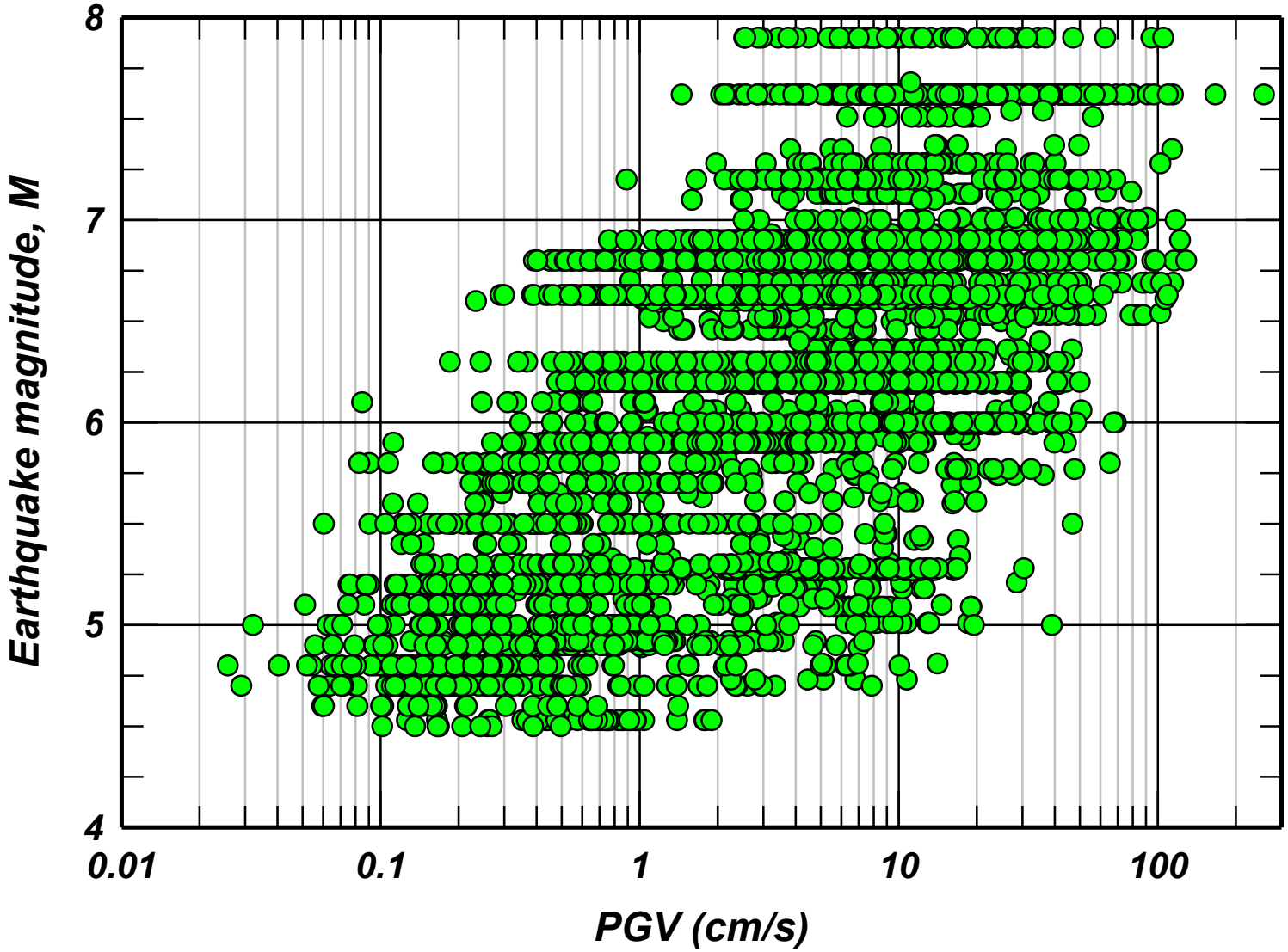
FF Records; Dist ≤ 160 km; M ≥ 4.5



FF Records; Dist ≤ 160 km; M ≥ 4.5



FF Records; Dist ≤ 160 km; M ≥ 4.5



DATA SET

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

Total Number of records used = 1288

[147 recordings (Vs30 ≥ 450 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 $V_{s30} > 1200$ m/s]

$$Ln(y) = (a_1 + a_2 M) - (b_1 + b_2 M) \lozenge Ln(R + 10) + gR + x(V_{s30} - 450) + f F$$

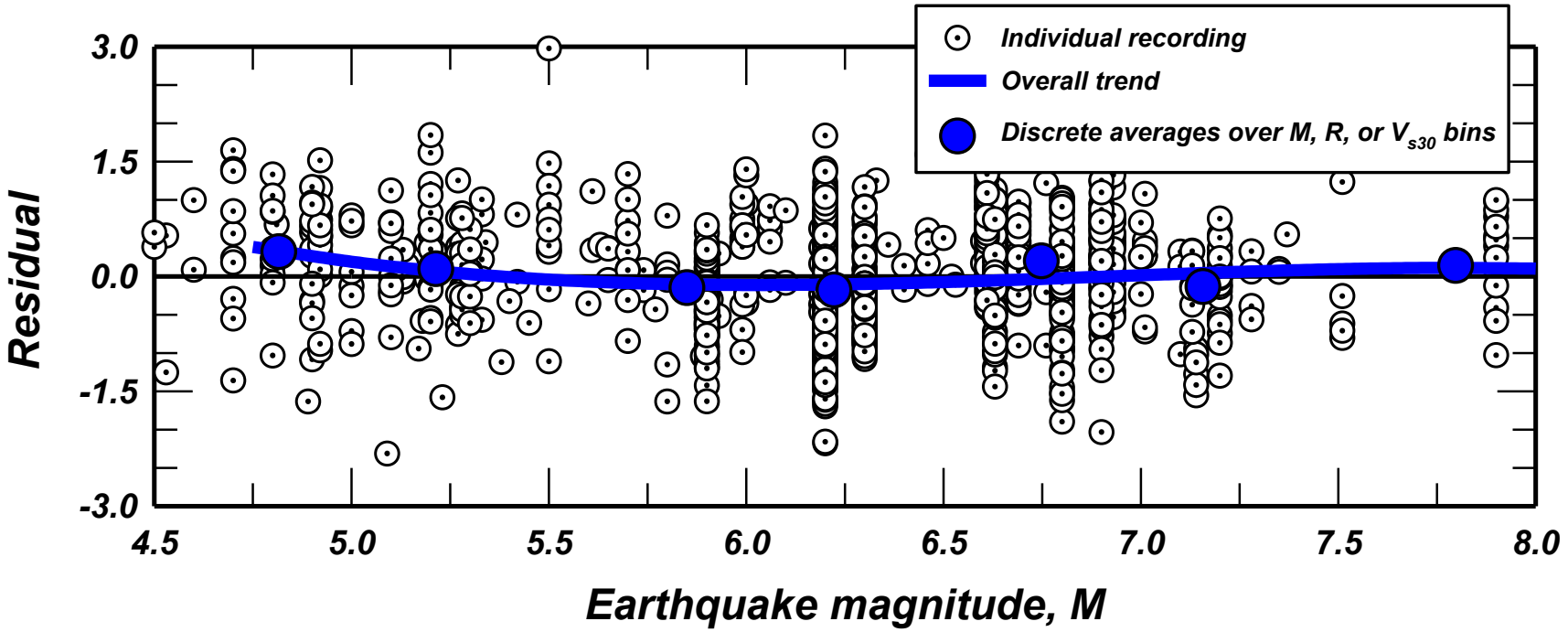
	Period (sec)	α_1	α_2	β_1	β_2	γ	ϕ	ξ
M > 6.75	0.01 (PGA)	5.5107	-0.3530	2.9832	-0.2339	-0.00125	0.12	**-0.00033**
	Period (sec)	α_1	α_2	β_1	β_2	γ	ϕ	ξ
M ≤ 6.75	0.01 (PGA)	3.5858	-0.0678	2.9832	-0.2339	-0.00125	0.12	**-0.00033**

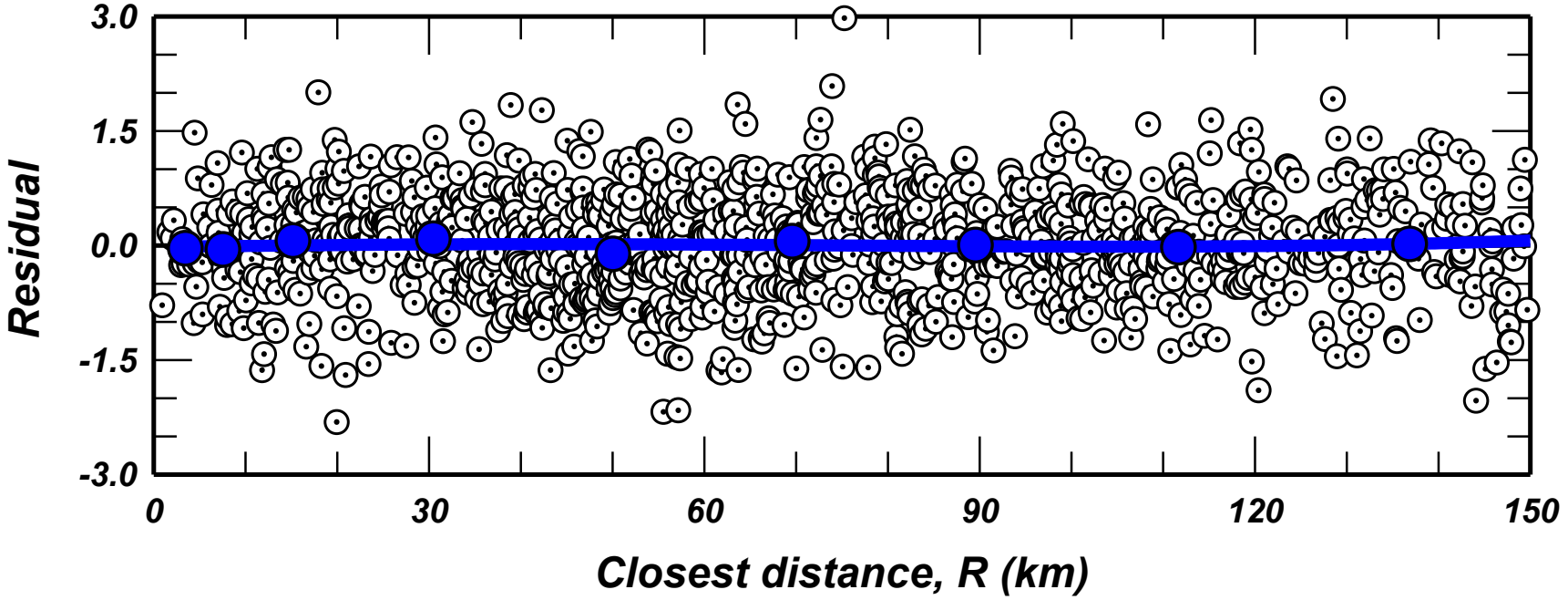
Range of M ==> ***4.5 to 8***

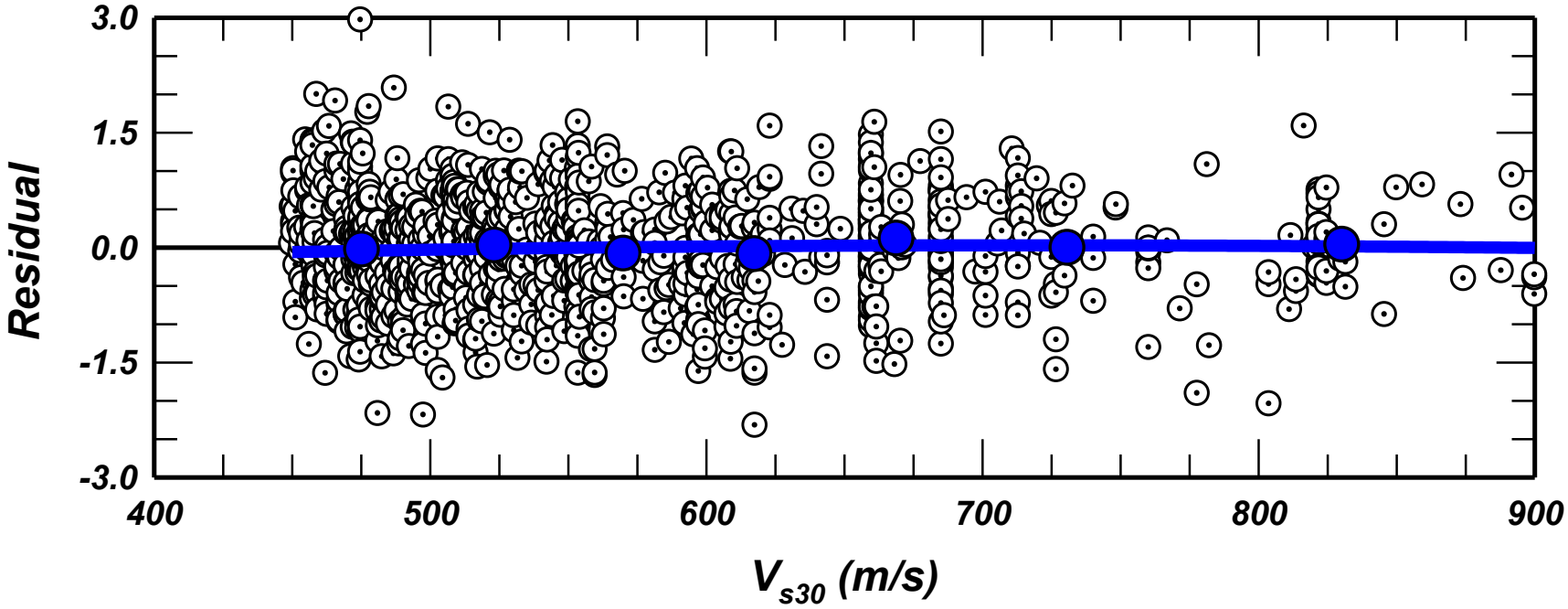
Range of R ==> ***0 to 160 km***

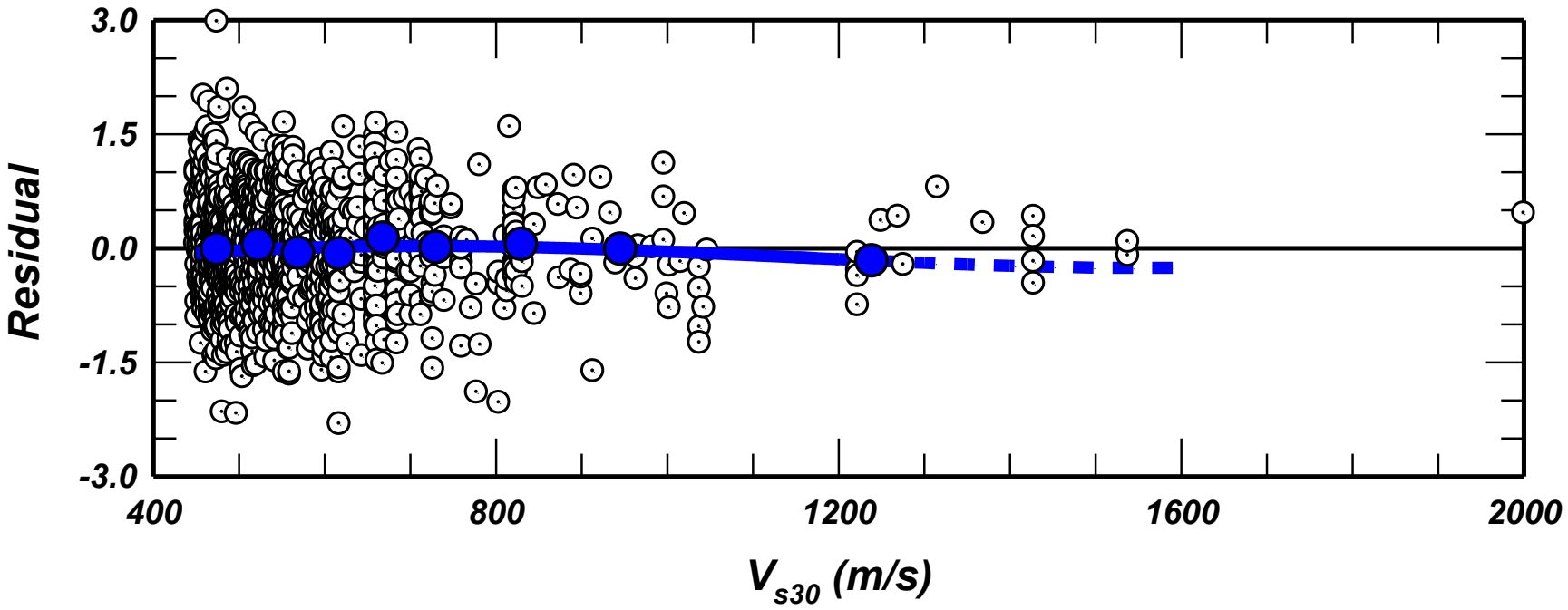
Range of Vs30 ==> ***450 ≤ to ≤ 2100 m/s***

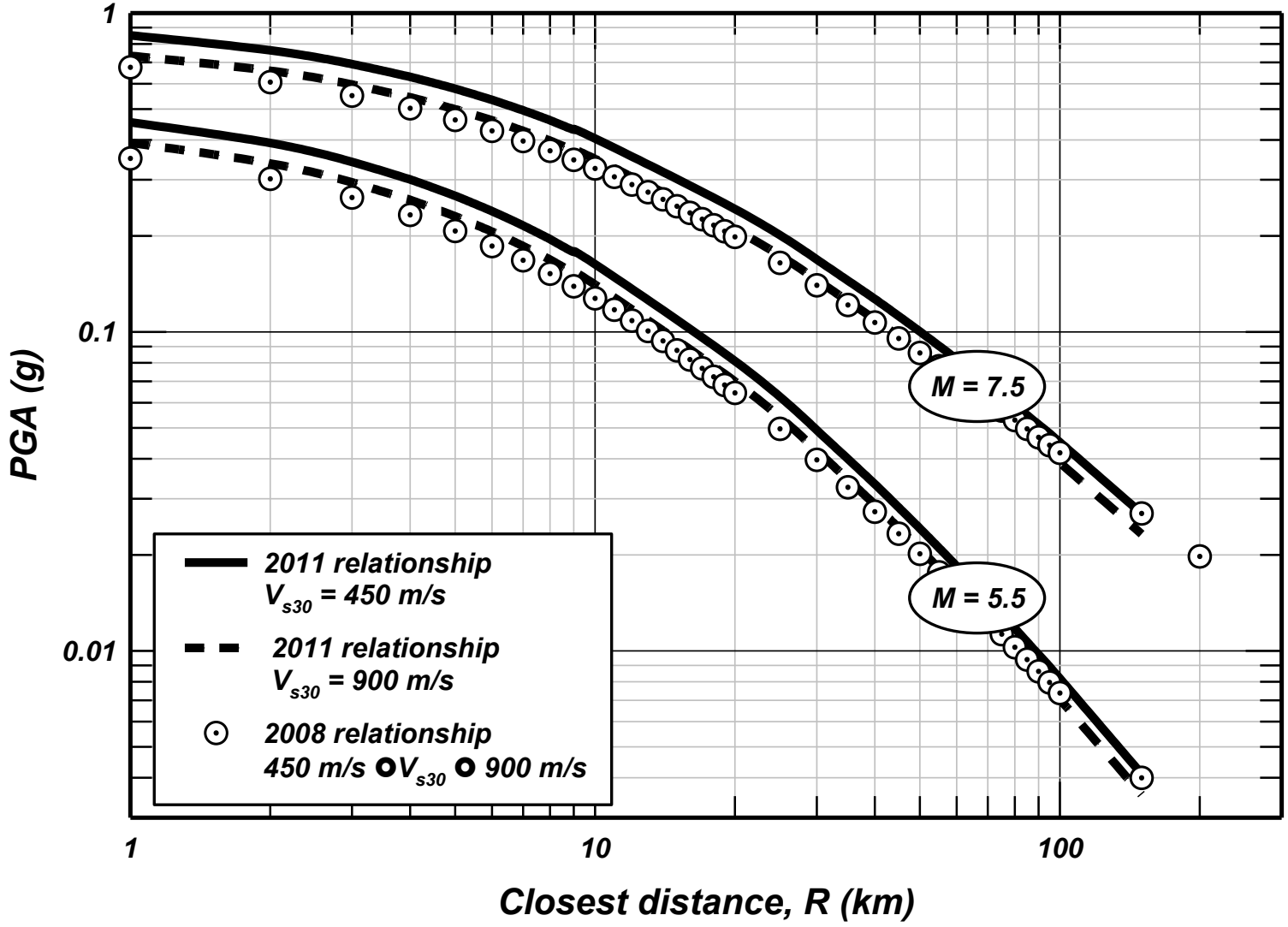
IMI_2011

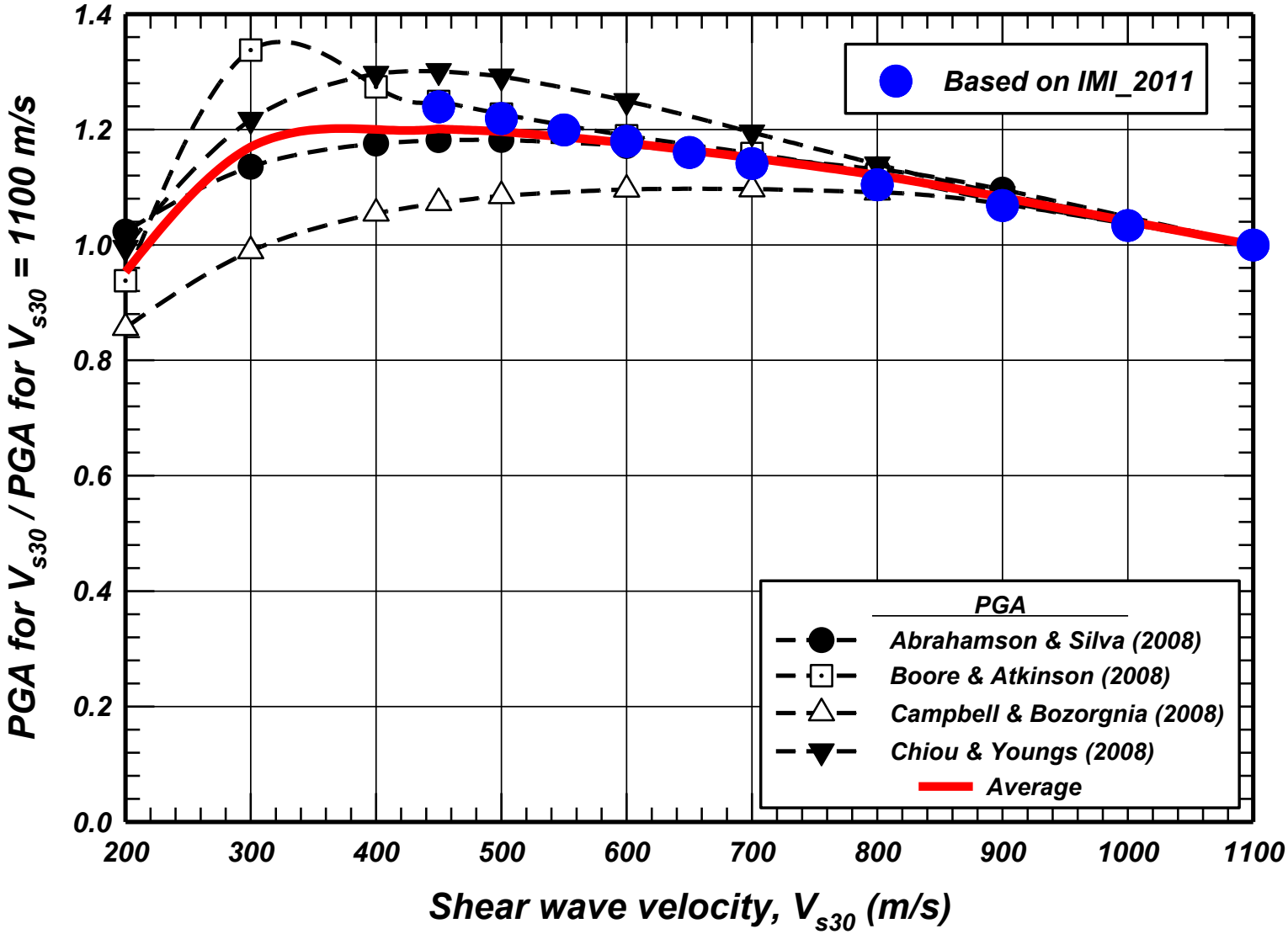

Individual recording
Overall trend
Discrete averages over M, R, or V_{s30} bins
Residual
3.0
1.5
0.0
-1.5
-3.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
Earthquake magnitude, M

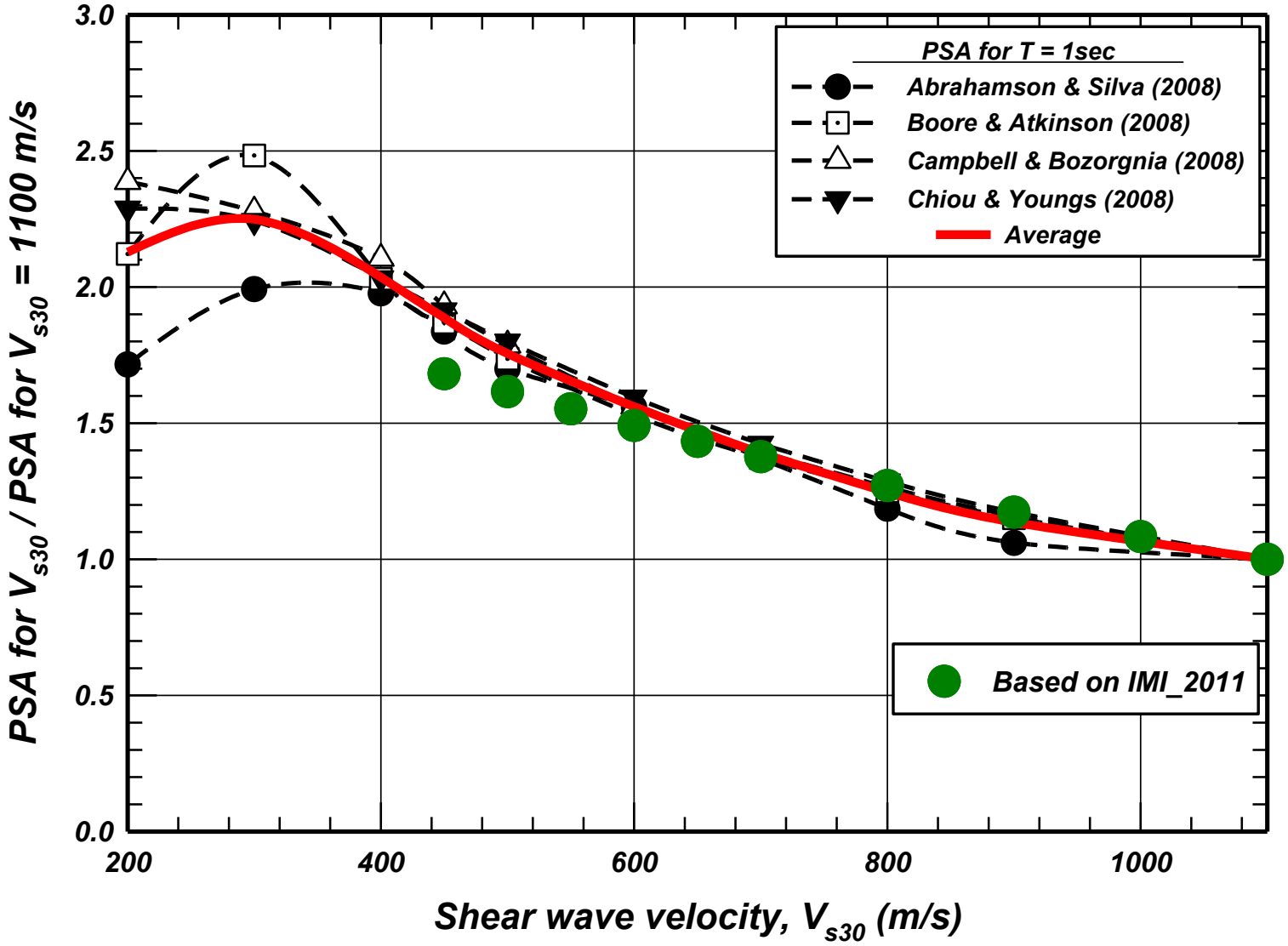

3.0
1.5
0.0
-1.5
-3.0
Residual
0
30
60
90
120
150
Closest distance, R (km)


3.0
1.5
0.0
-1.5
-3.0
Residual
400
500
600
700
800
900
V_{s30} (m/s)


3.0
1.5
0.0
-1.5
-3.0
Residual
400
800
1200
1600
2000
V_{s30} (m/s)


1
0.1
0.01
PGA (g)
M = 7.5
M = 5.5
2011 relationship
V_{s30} = 450 m/s
2011 relationship
V_{s30} = 900 m/s
2008 relationship
450 m/s ≤ V_{s30} ≤ 900 m/s
1
10
100
Closest distance, R (km)


PGA for V_{s30} / PGA for V_{s30} = 1100 m/s
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
200
300
400
500
600
700
800
900
1000
1100
Shear wave velocity, V_{s30} (m/s)
Based on IMI_2011
PGA
Abrahamson & Silva (2008)
Boore & Atkinson (2008)
Campbell & Bozorgnia (2008)
Chiou & Youngs (2008)
Average


PSA for T = 1sec
Abrahamson & Silva (2008)
Boore & Atkinson (2008)
Campbell & Bozorgnia (2008)
Chiou & Youngs (2008)
Average
Based on IMI_2011
PSA for V_{s30} / PSA for V_{s30} = 1100 m/s
Shear wave velocity, V_{s30} (m/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200
400
600
800
1000

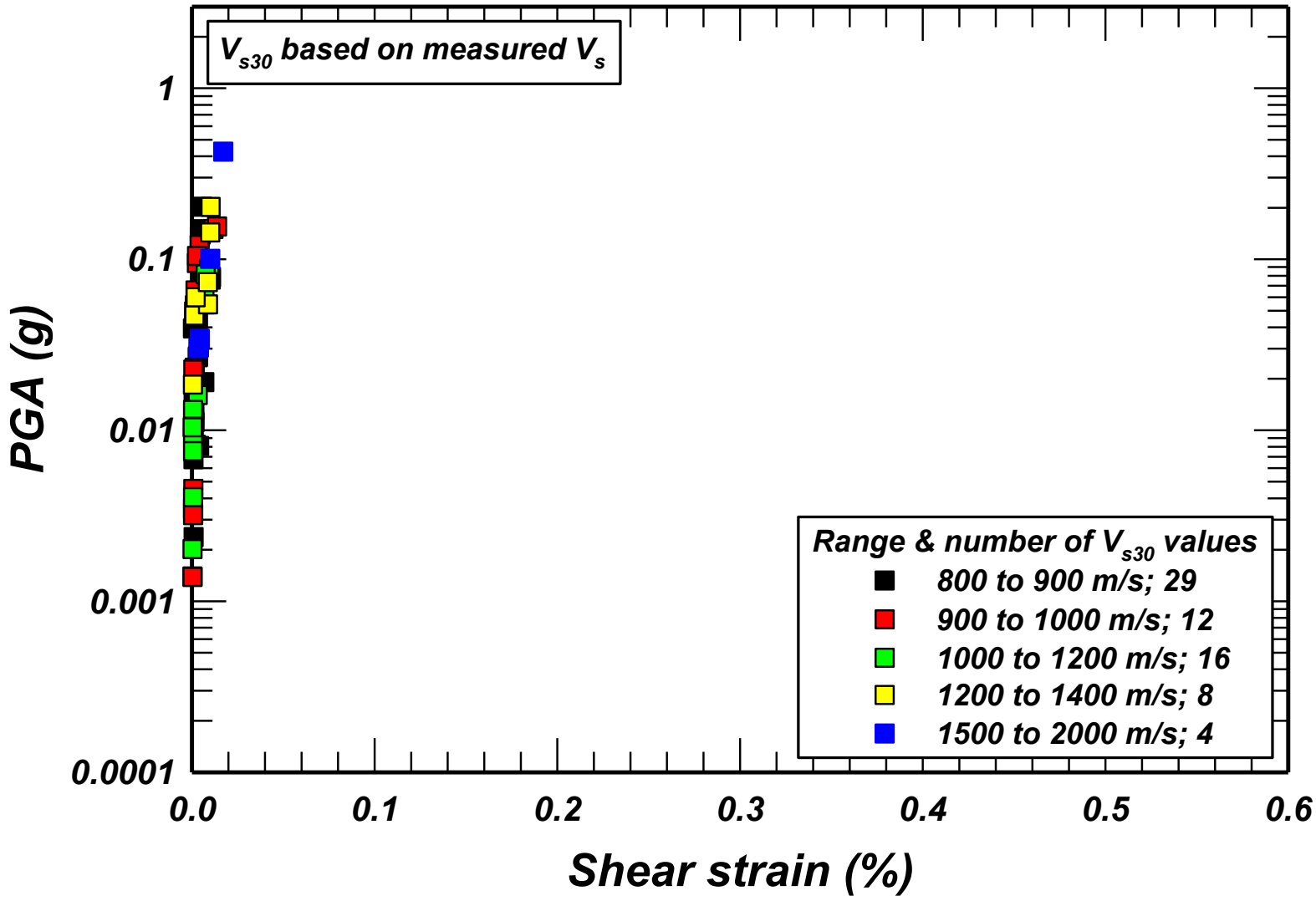
WHAT DO THE NGA DATA SHOW?

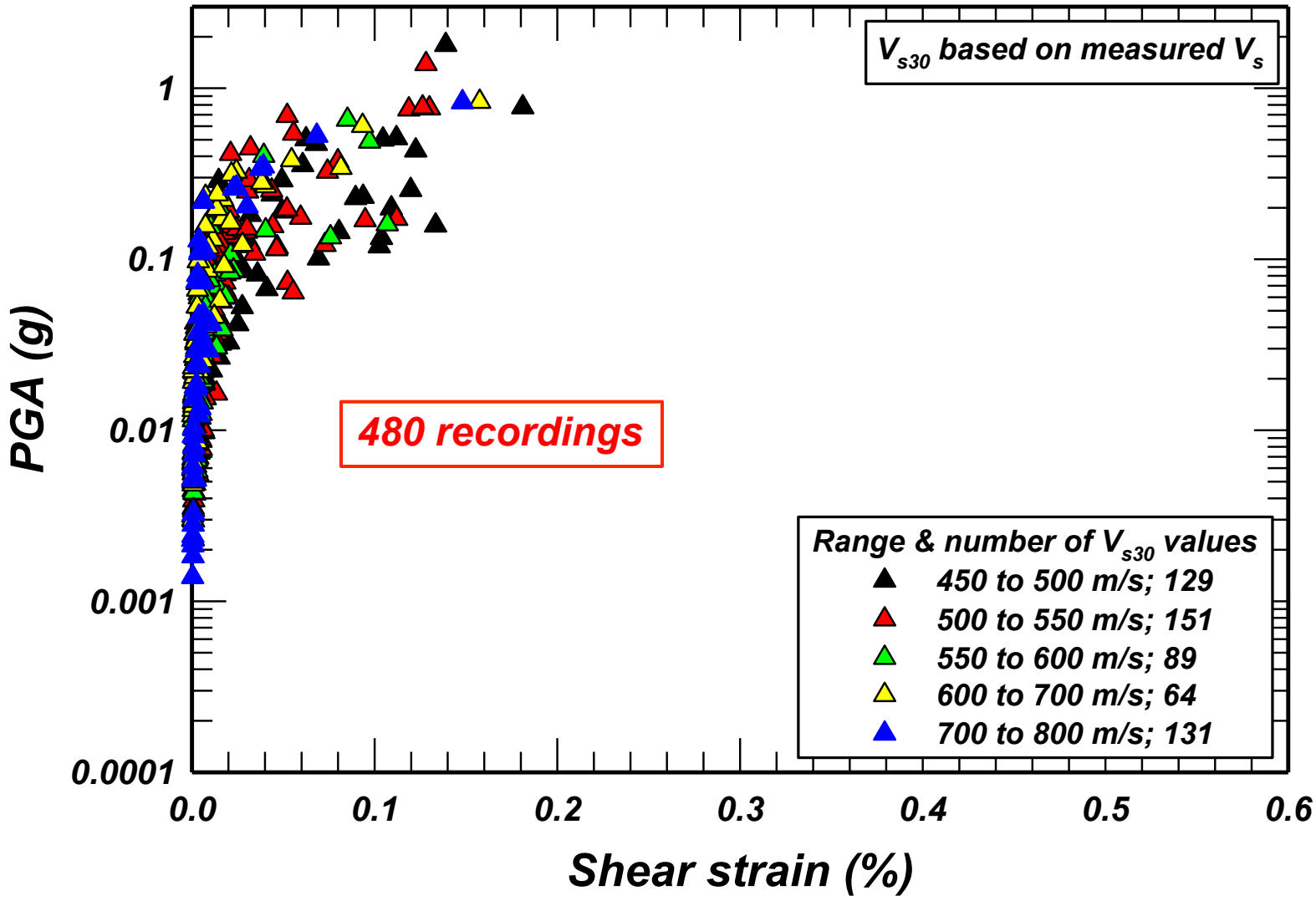
Examination in terms of the ratio of:

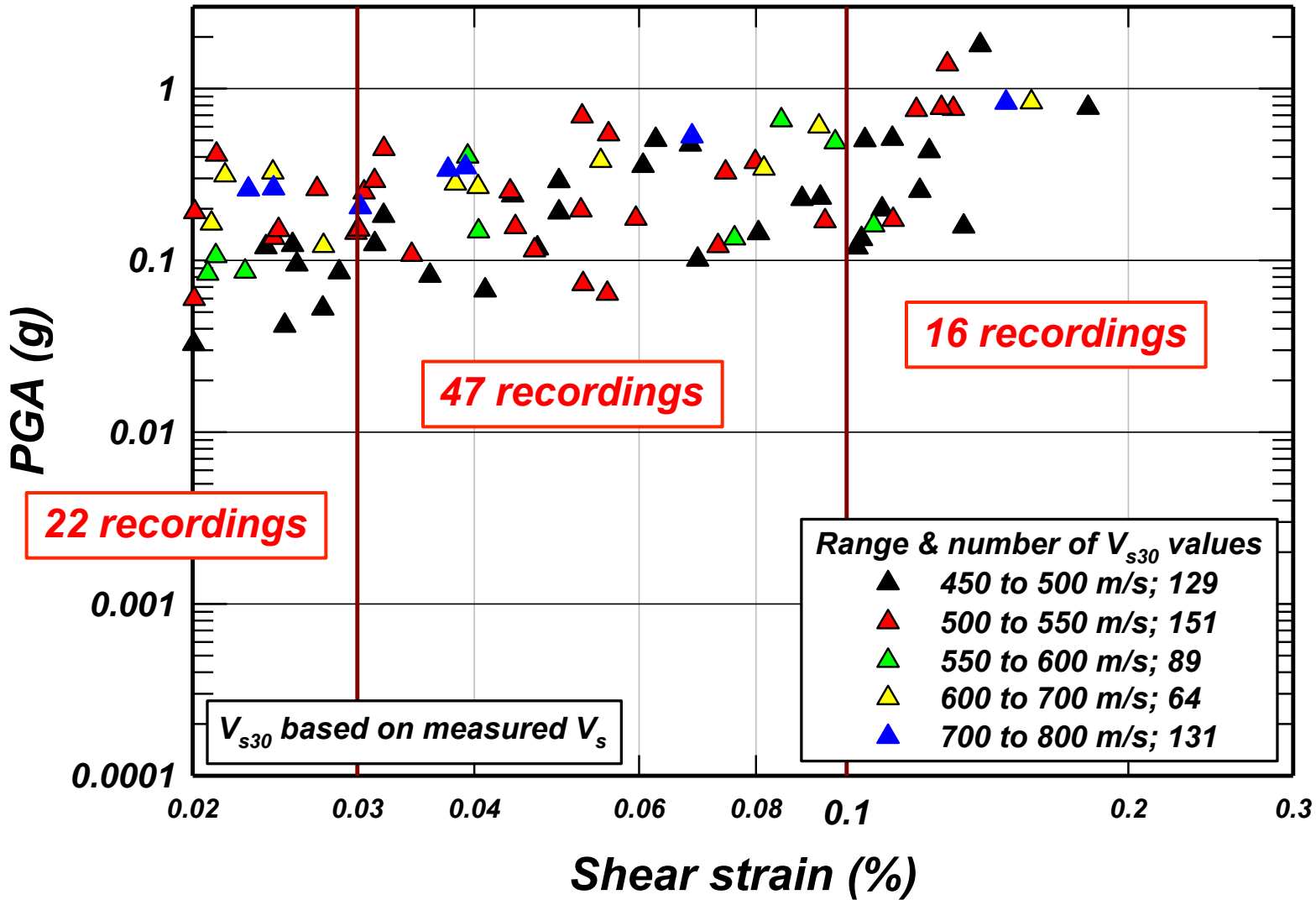
$$PGV/V_{s30}$$

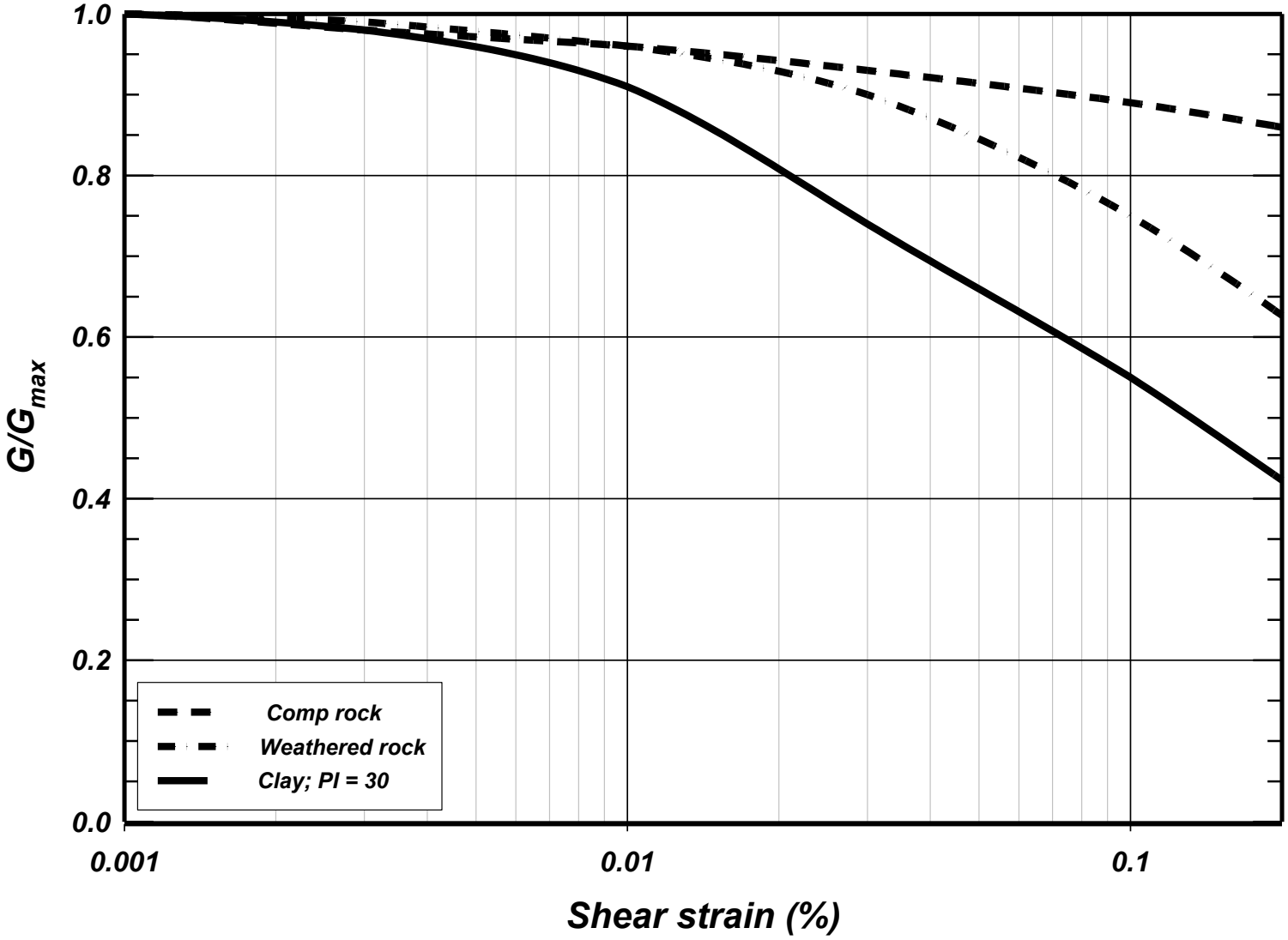
which may be considered as a "proxy" for shear strain induced by the earthquake ground motions

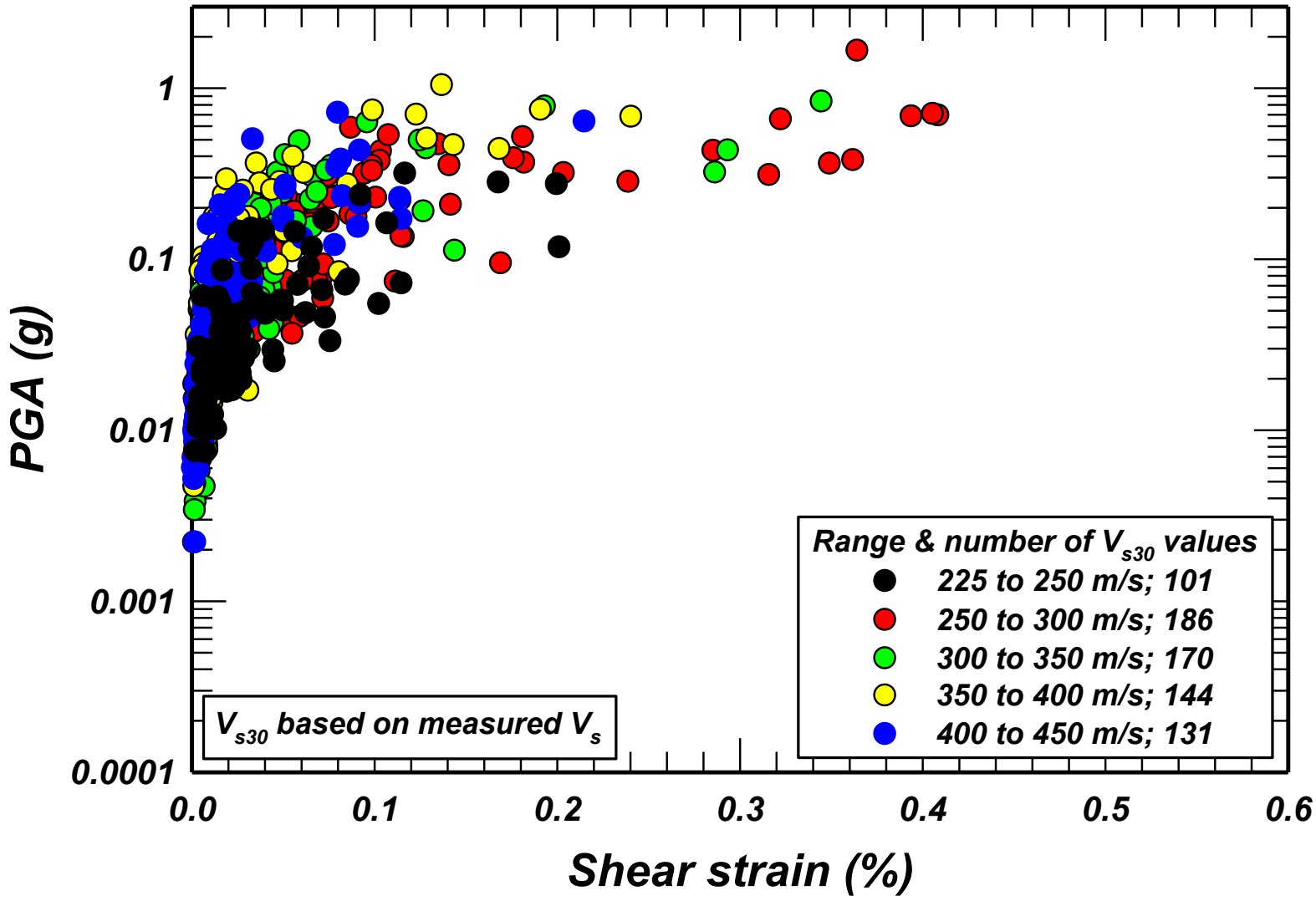
Plotting PGA versus this ratio can then be examined as if it were a "stress- strain" relationship

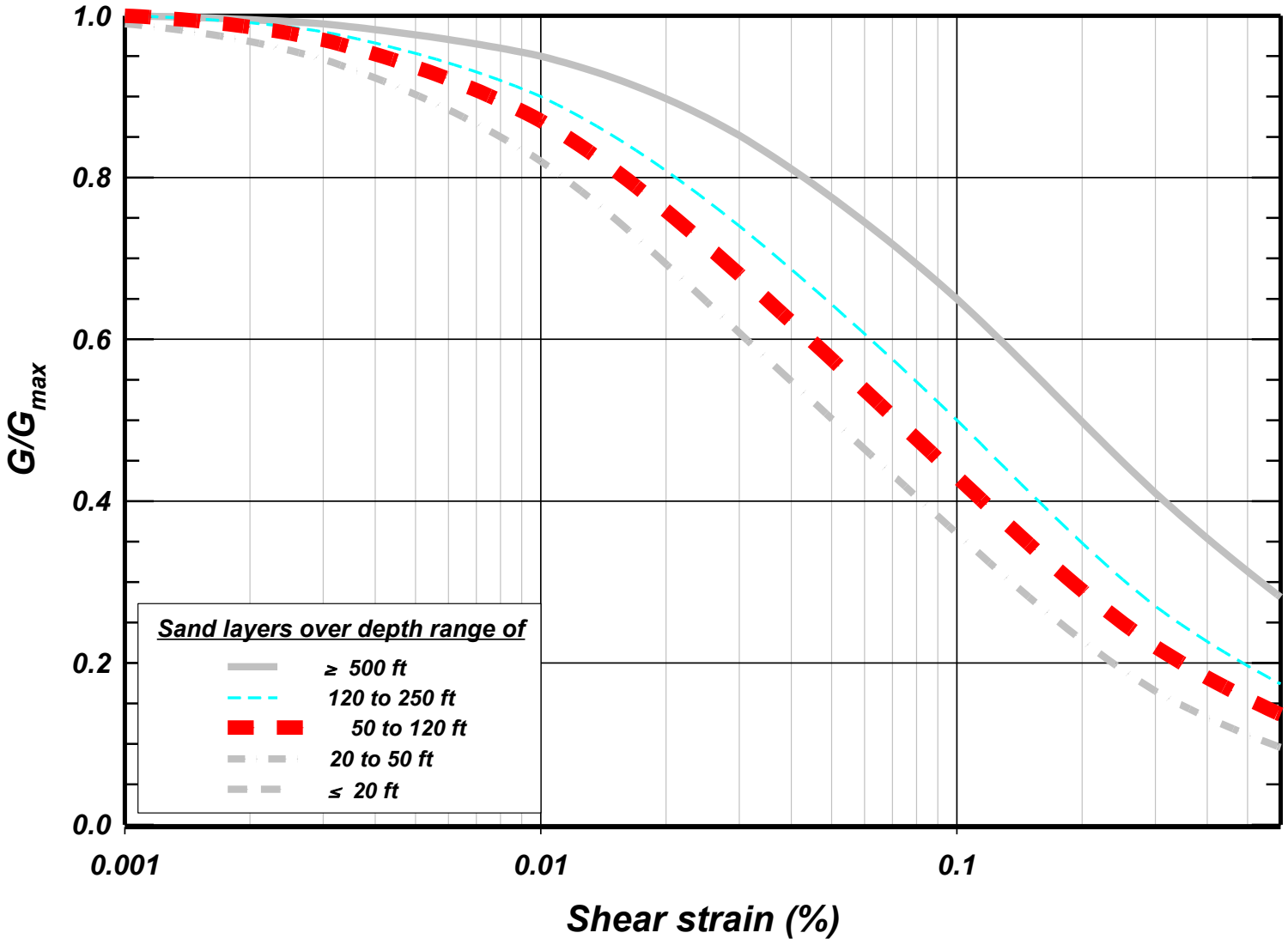

V_{s30} based on measured V_s
1
0.1
0.01
0.001
0.0001
PGA (g)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Shear strain (%)
Range & number of V_{s30} values
800 to 900 m/s; 29
900 to 1000 m/s; 12
1000 to 1200 m/s; 16
1200 to 1400 m/s; 8
1500 to 2000 m/s; 4

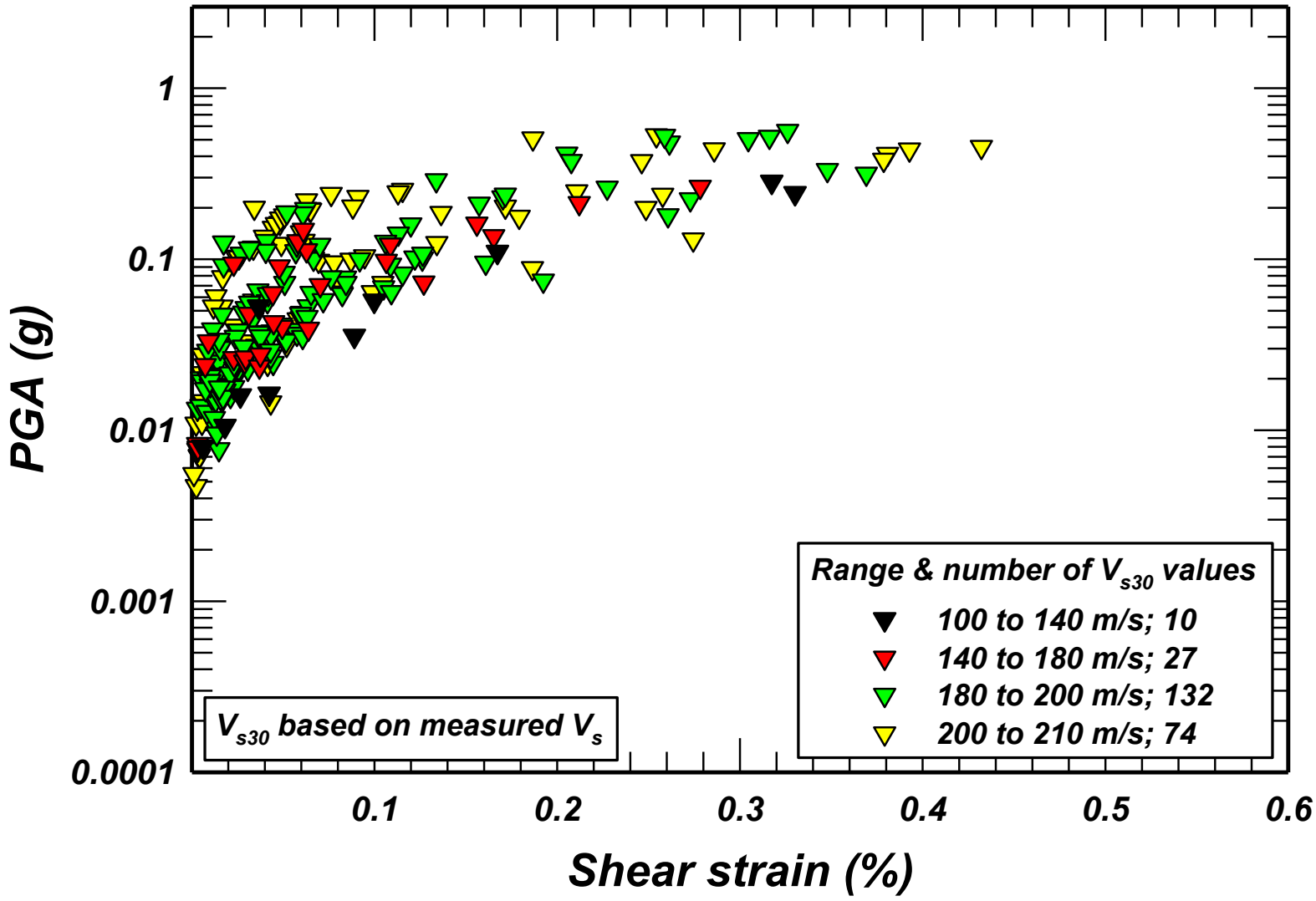

V_{s30} based on measured V_s
480 recordings
Range & number of V_{s30} values
450 to 500 m/s; 129
500 to 550 m/s; 151
550 to 600 m/s; 89
600 to 700 m/s; 64
700 to 800 m/s; 131
PGA (g)
1
0.1
0.01
0.001
0.0001
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Shear strain (%)


PGA (g)
1
0.1
0.01
0.001
0.0001
0.02
0.03
0.04
0.06
0.08
0.1
0.2
0.3
Shear strain (%)
22 recordings
47 recordings
16 recordings
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


1.0
0.8
0.6
0.4
0.2
0.0
G/Gmax
0.001
0.01
0.1
Shear strain (%)
Comp rock
Weathered rock
Clay; PI = 30


PGA (g)
1
0.1
0.01
0.001
0.0001
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Shear strain (%)
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


1.0
0.8
0.6
0.4
0.2
0.0
G/Gmax
0.001
0.01
0.1
Shear strain (%)
Sand layers over depth range of
≥ 500 ft
120 to 250 ft
50 to 120 ft
20 to 50 ft
≤ 20 ft


PGA (g)
1
0.1
0.01
0.001
0.0001
0.1
0.2
0.3
0.4
0.5
0.6
Shear strain (%)
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

Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

March 11-15, 1991

St. Louis, MO 1991

Vol. III

Editor: Shamsher Prakash

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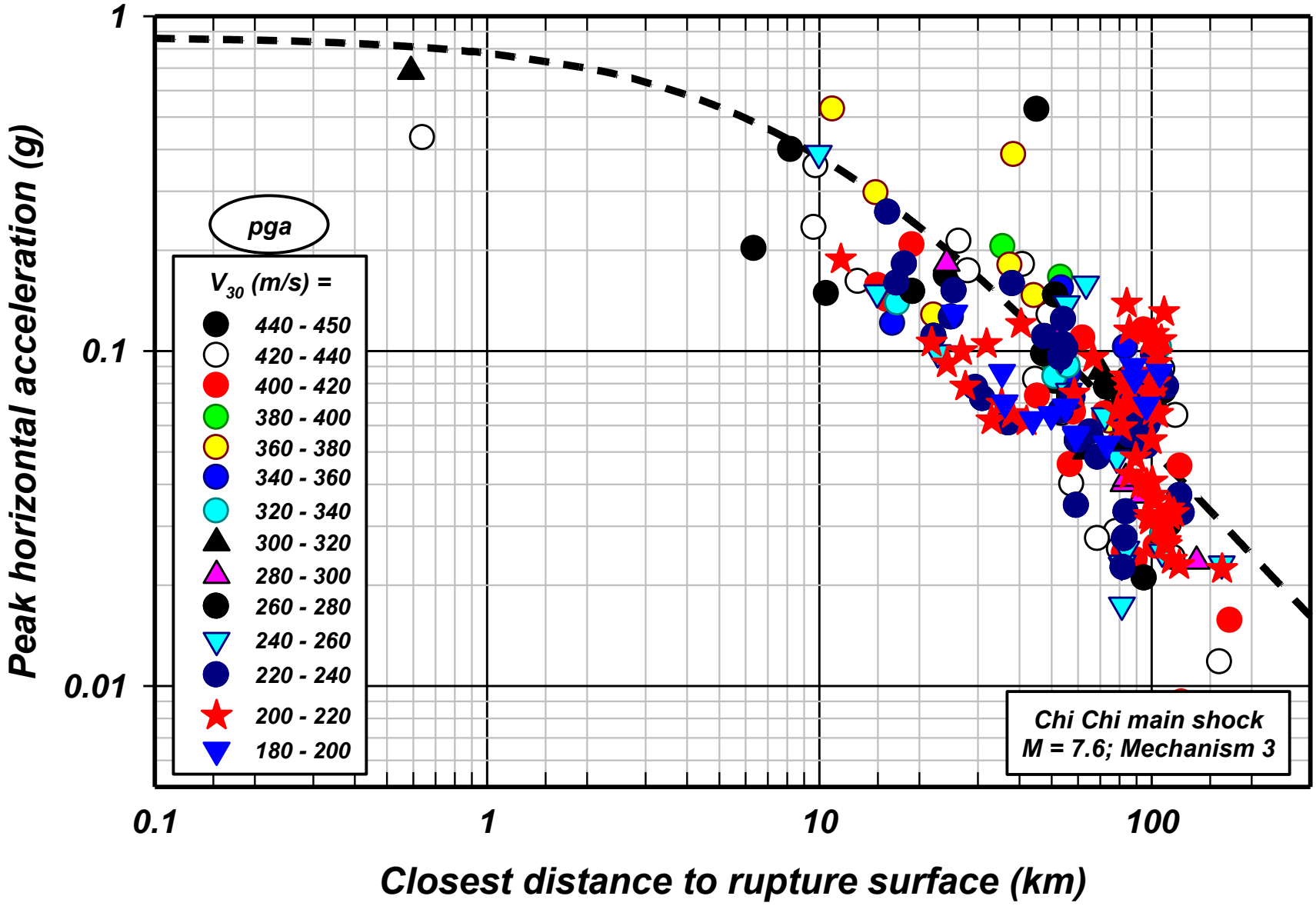
Rolla, Missouri

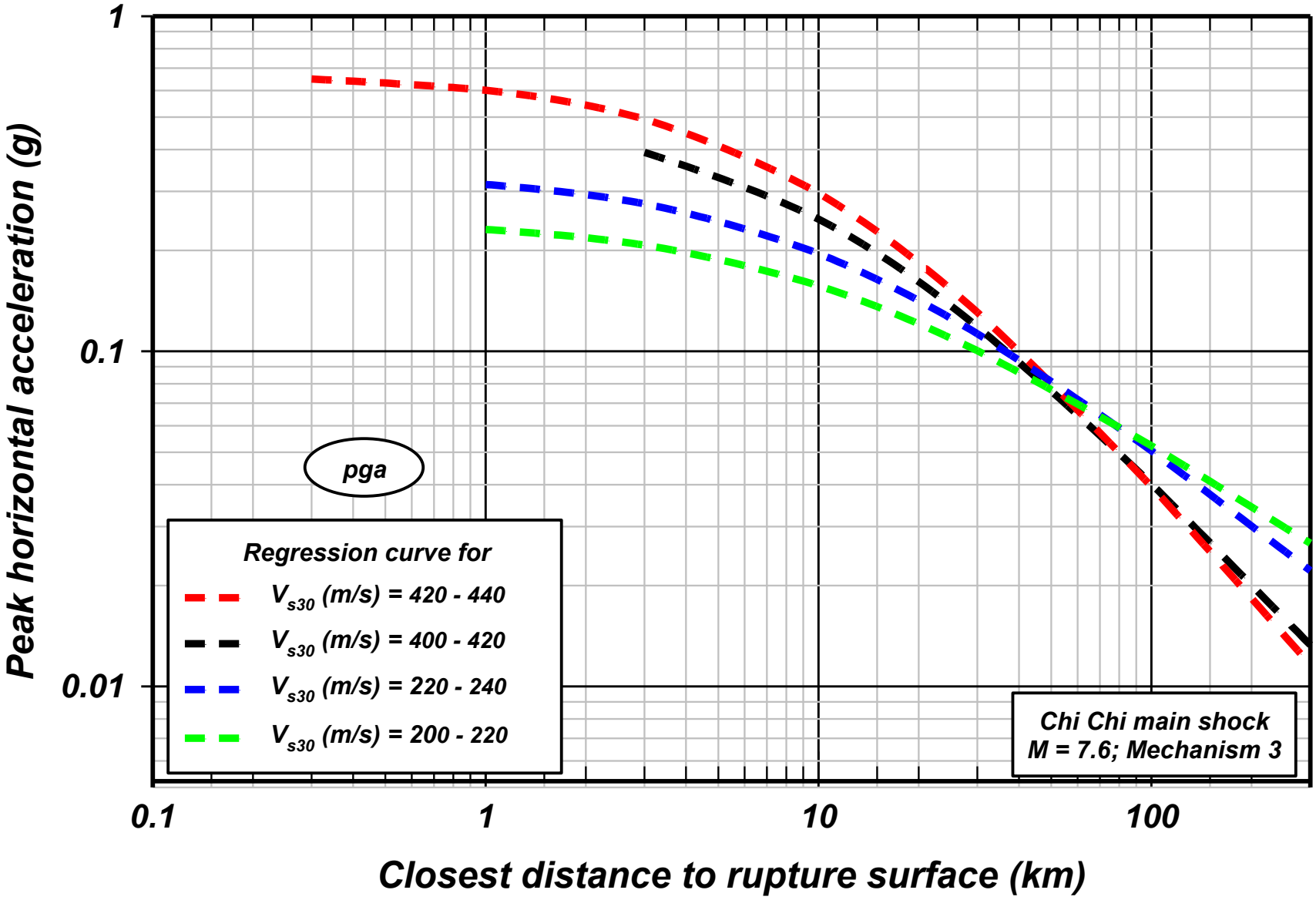
Examination in terms of :

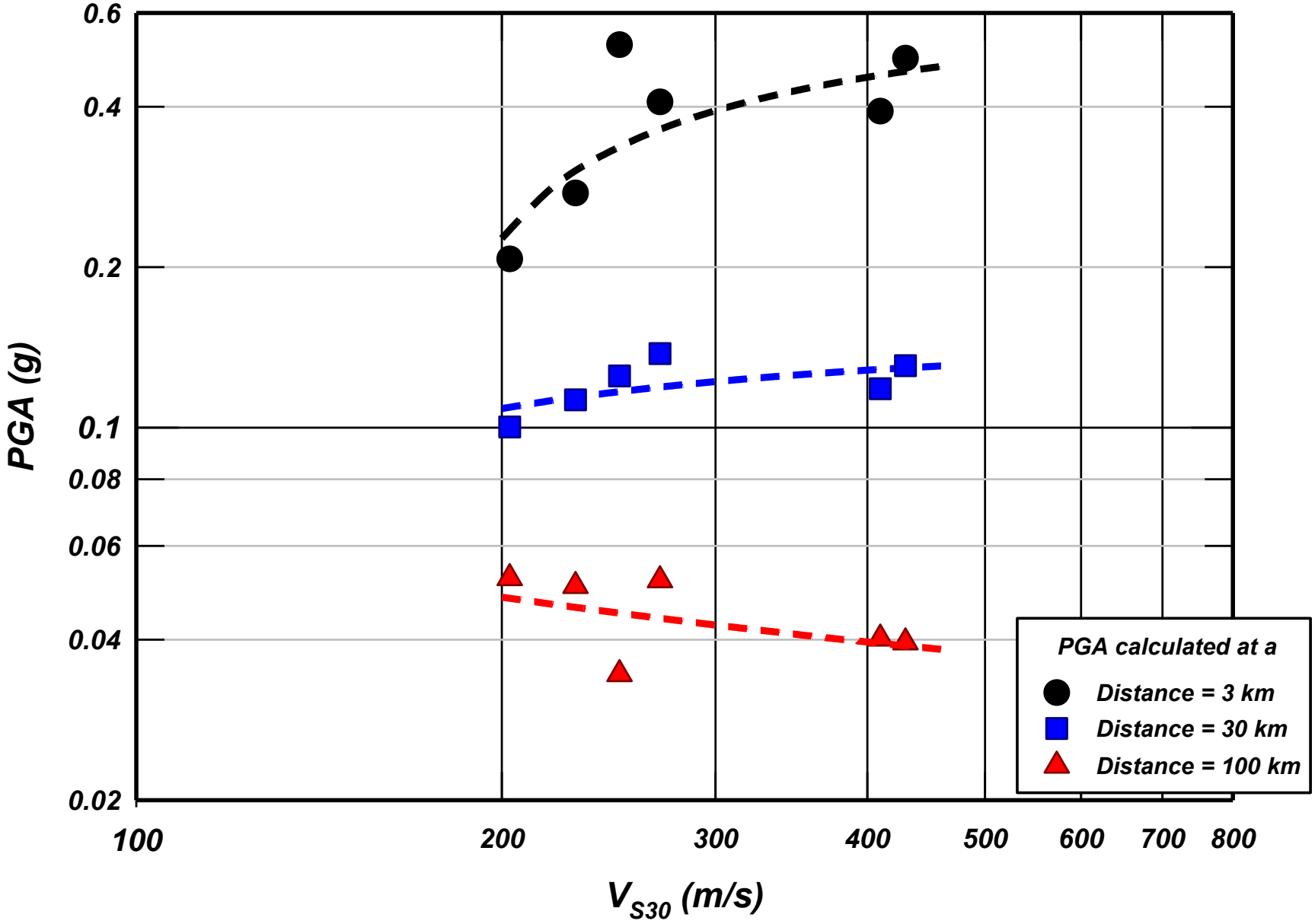
Variations of PGA and PSA, at T = 1 sec, with Distance

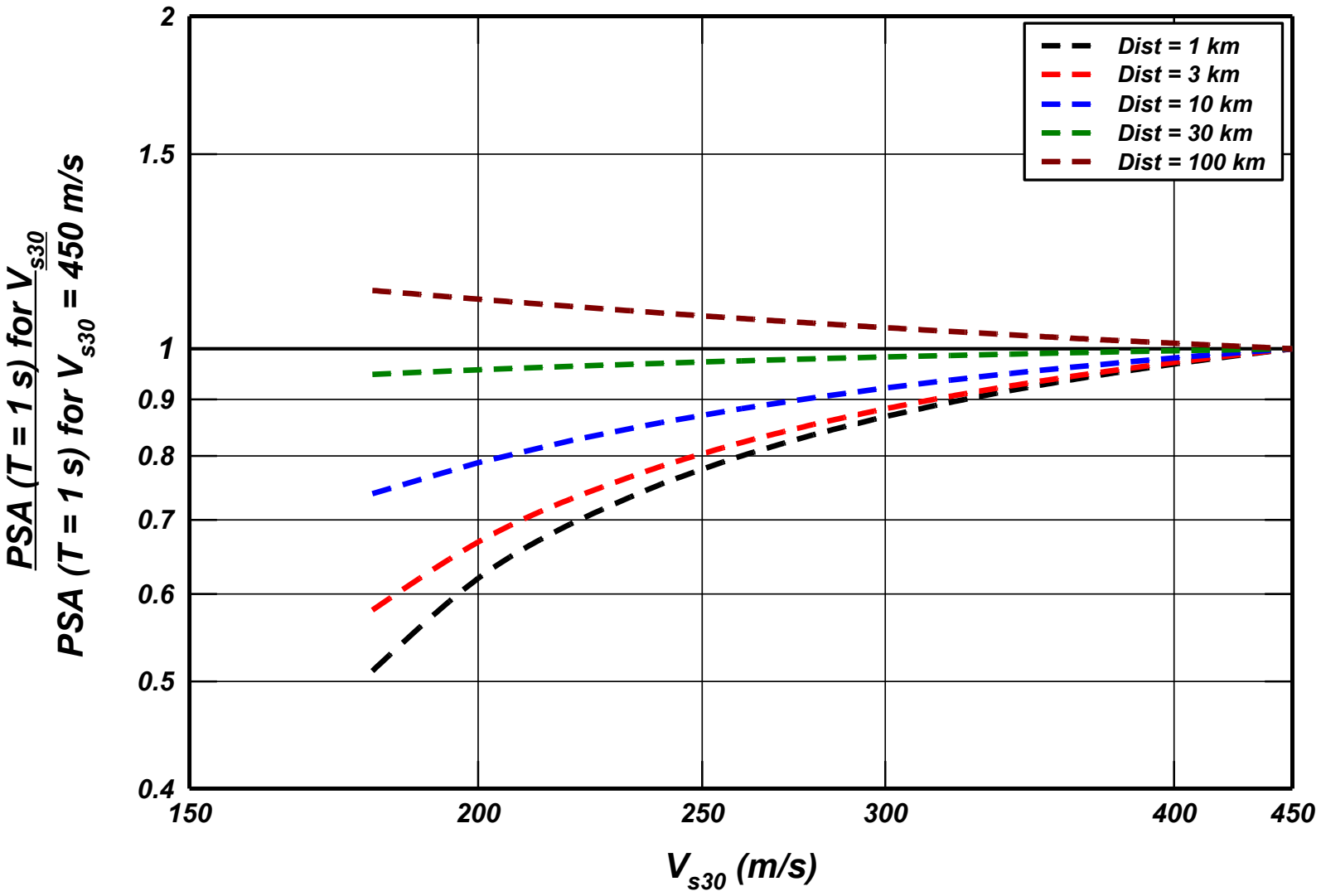
For various bins of V_{s30}

Chi-Chi main shock data


1
0.1
0.01
Peak horizontal acceleration (g)
pga
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
Chi Chi main shock
M = 7.6; Mechanism 3
0.1
1
10
100
Closest distance to rupture surface (km)

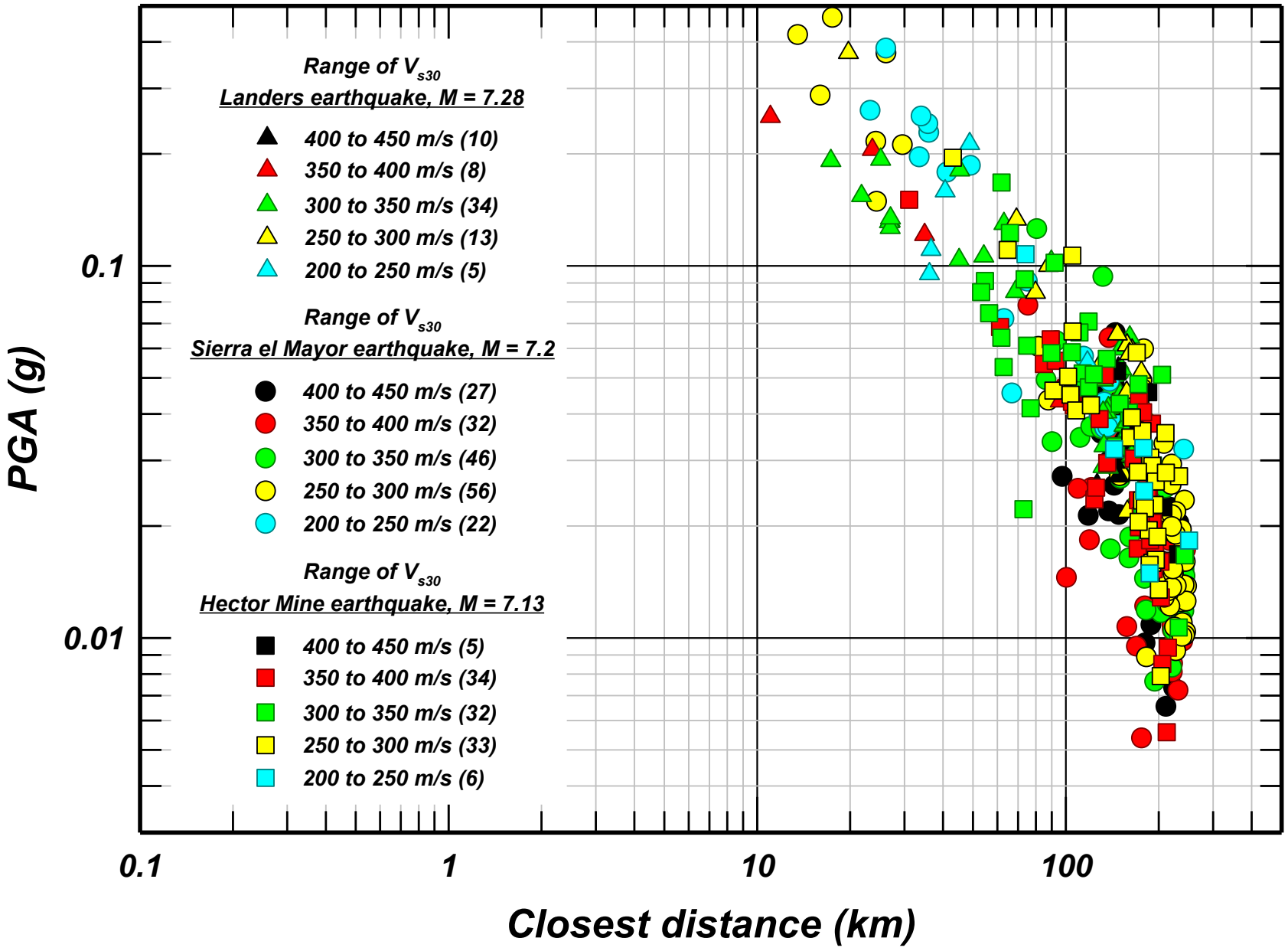

1
0.1
0.01
Peak horizontal acceleration (g)
pga
Regression curve for
V_{s30} (m/s) = 420 - 440
V_{s30} (m/s) = 400 - 420
V_{s30} (m/s) = 220 - 240
V_{s30} (m/s) = 200 - 220
Chi Chi main shock
M = 7.6; Mechanism 3
0.1
1
10
100
Closest distance to rupture surface (km)

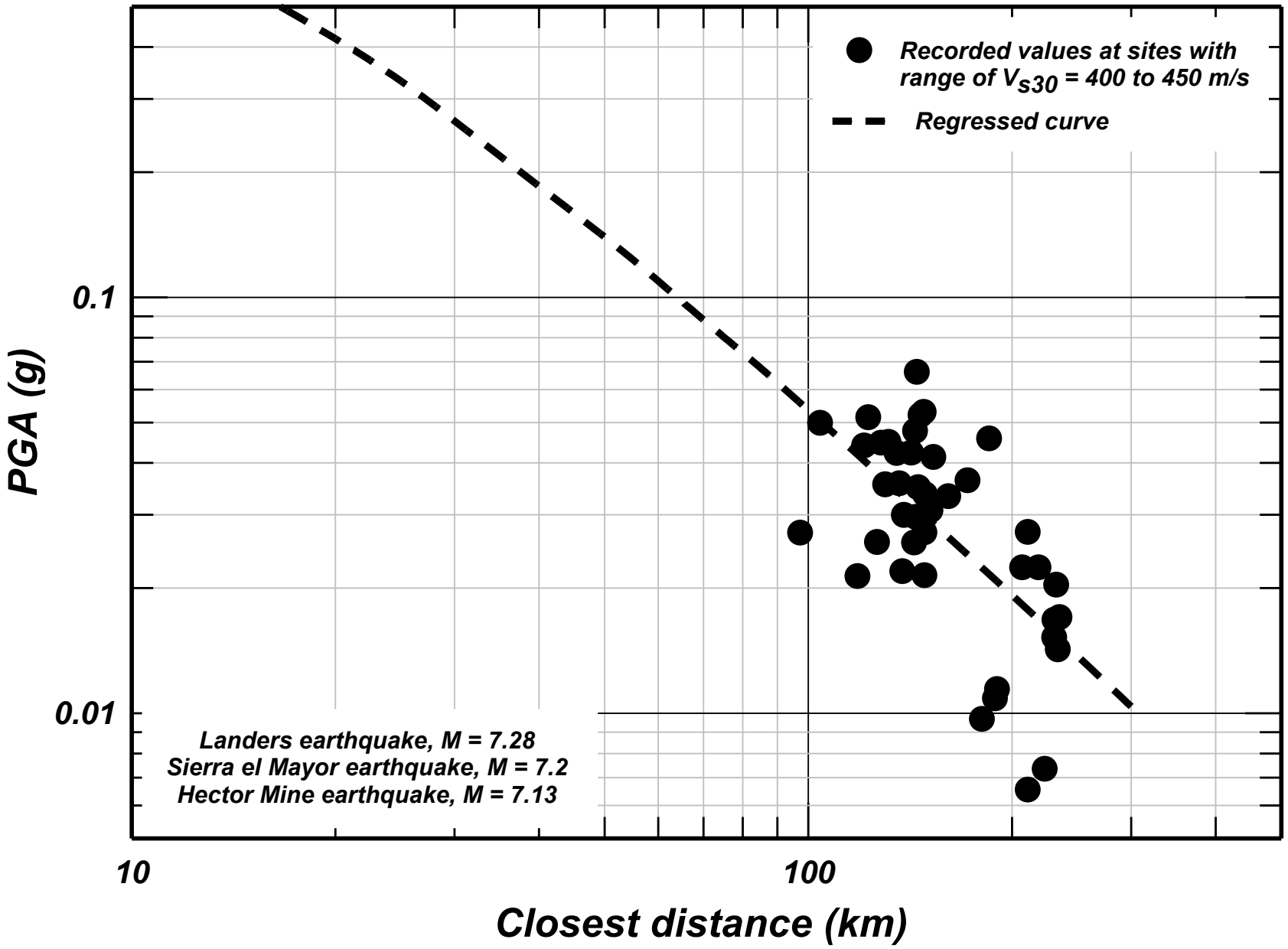

0.6
0.4
0.2
0.1
0.08
0.06
0.04
0.02
PGA (g)
100
200
300
400
500
600
700
800
V_{S30} (m/s)
PGA calculated at a
Distance = 3 km
Distance = 30 km
Distance = 100 km

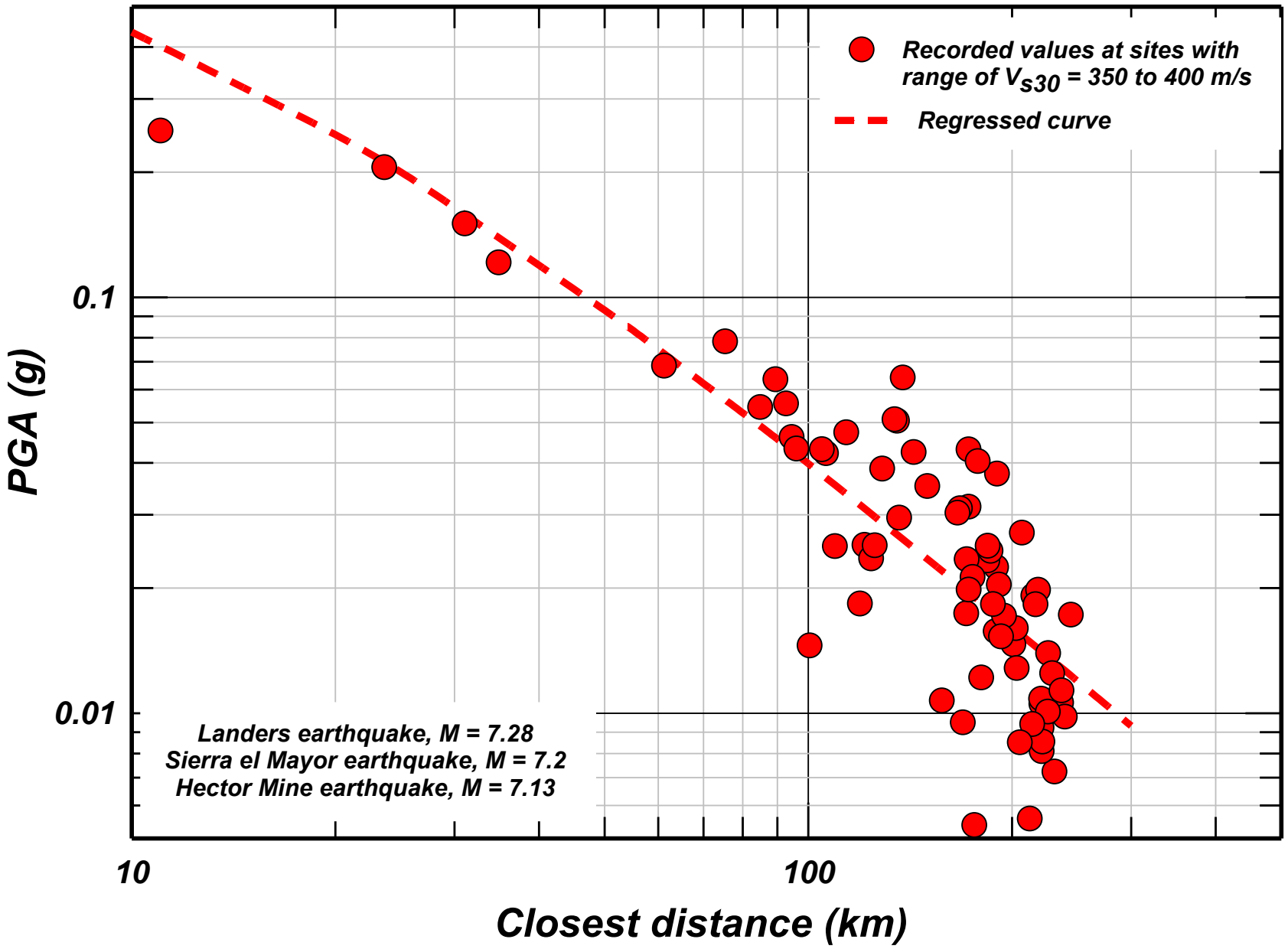


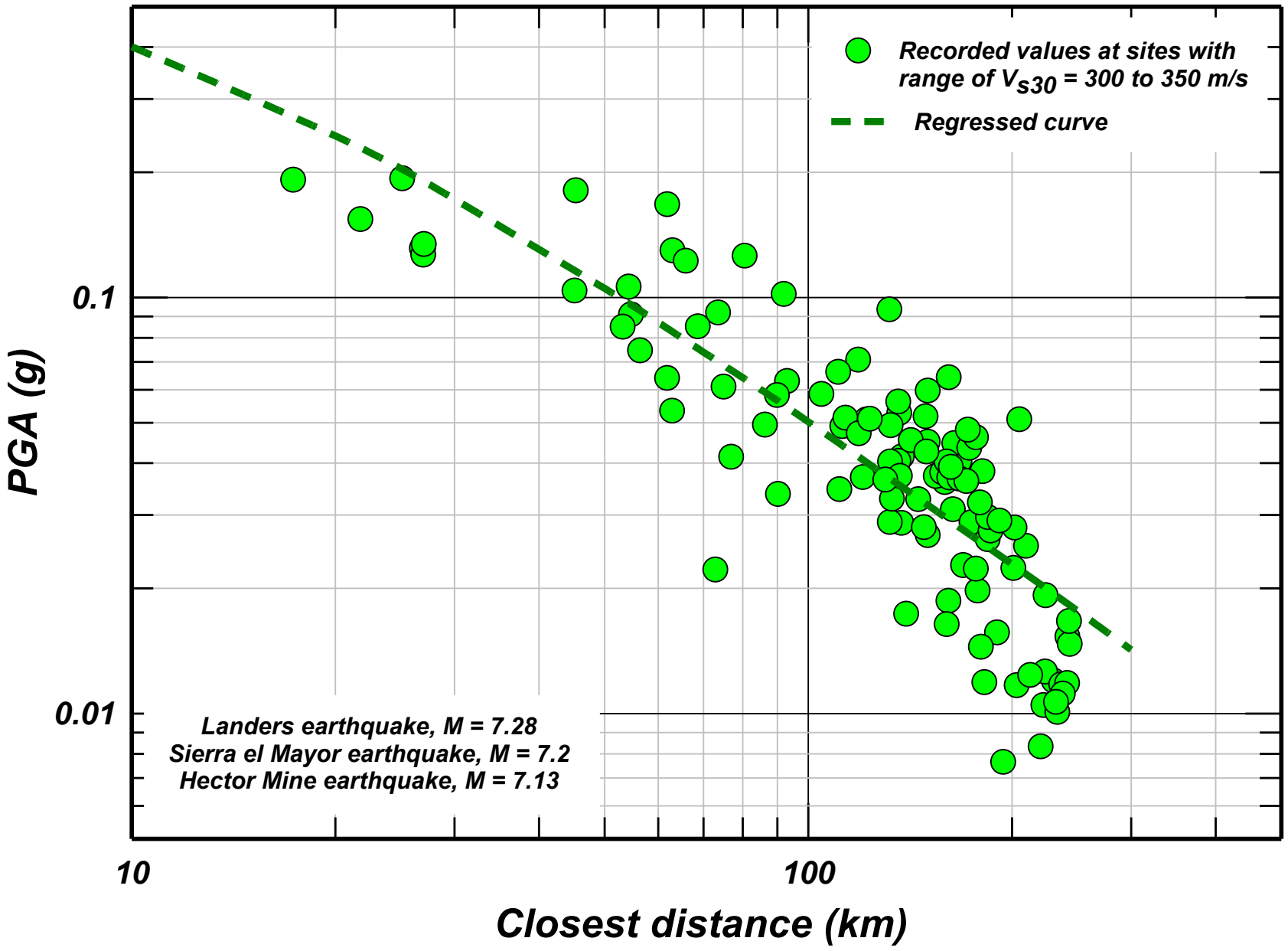
Based on Chi-Chi Recordings

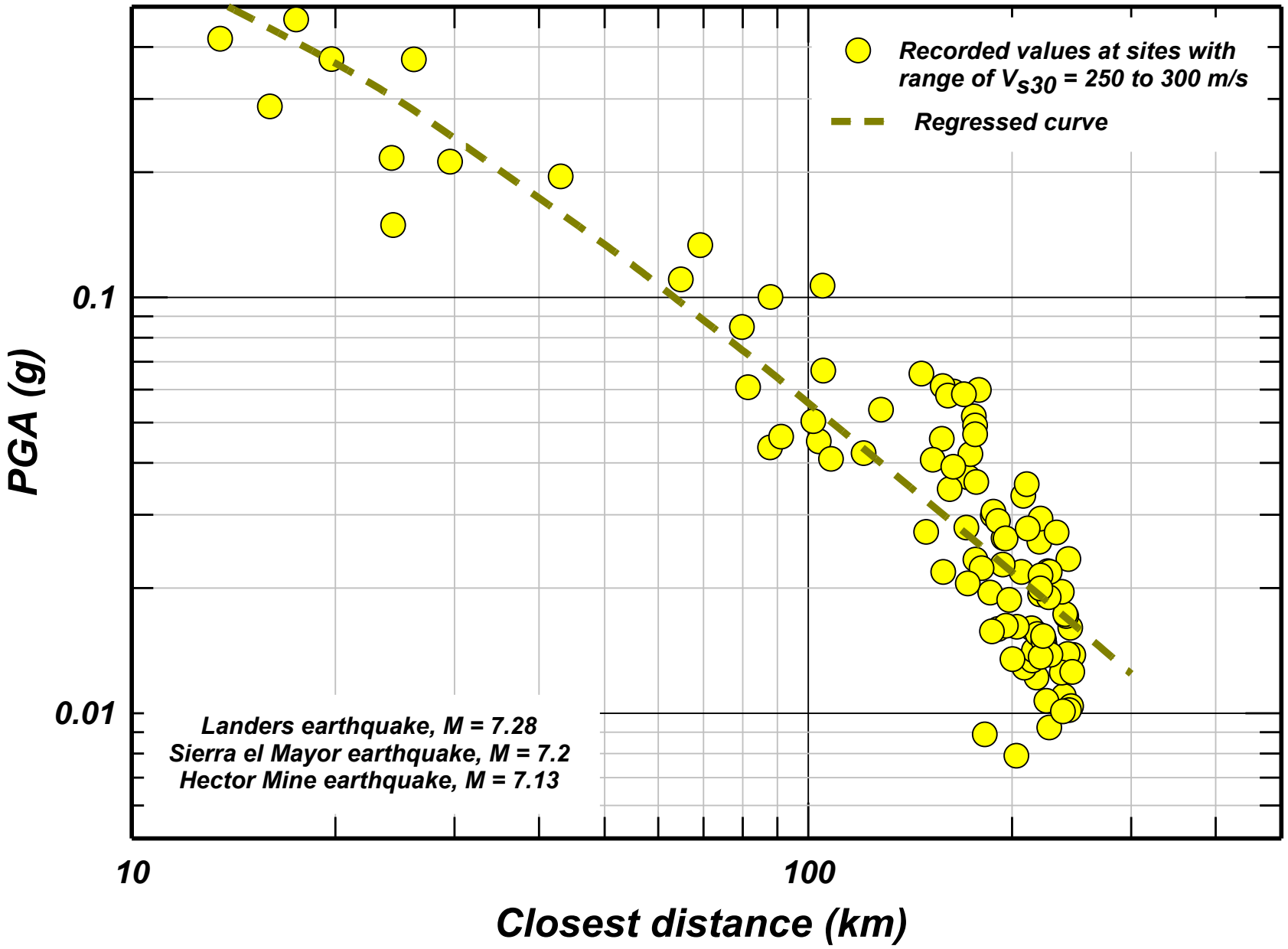
Based on recorded data from other than the Chi-Chi earthquake

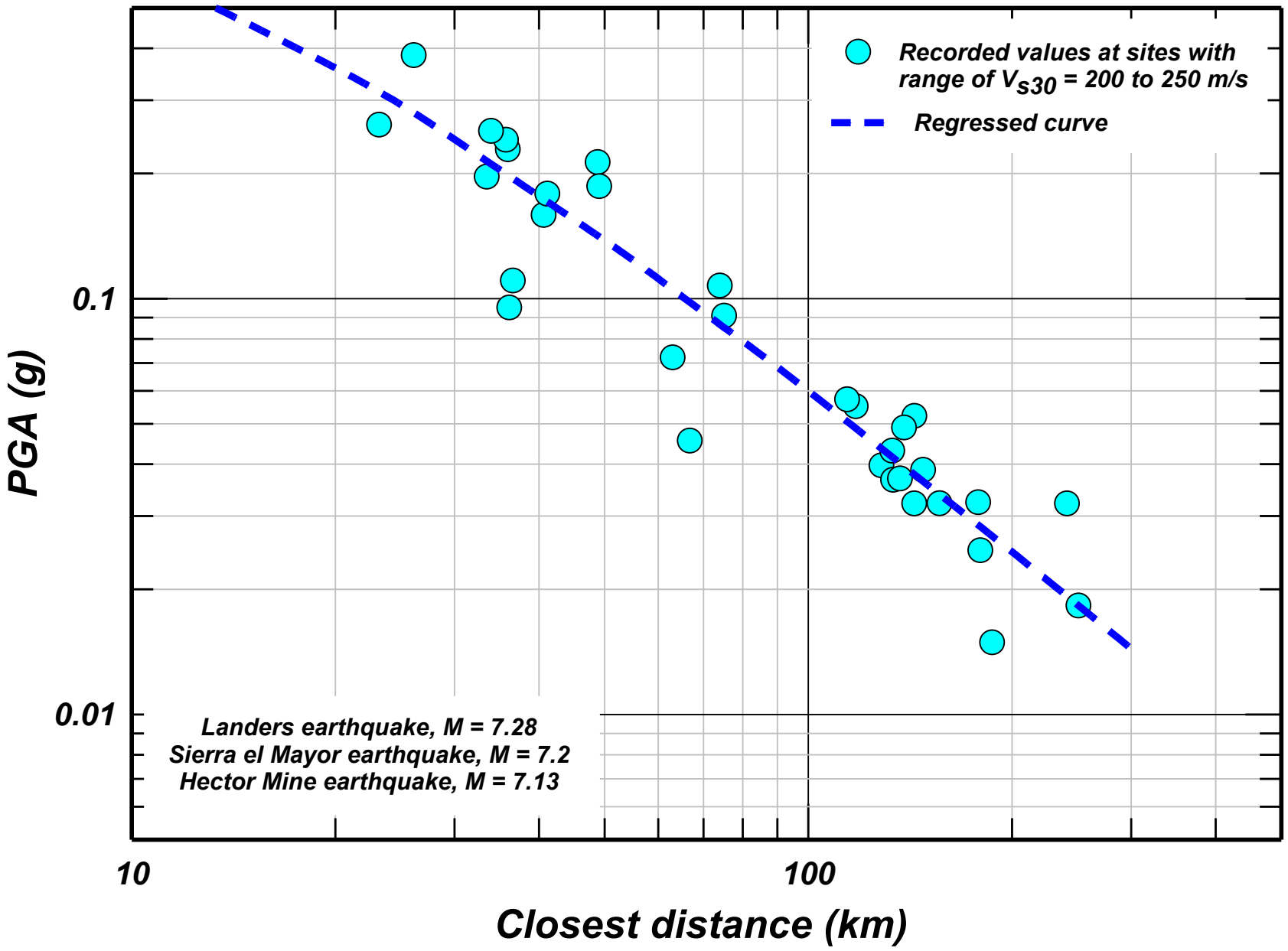

Range of V_{s30}
Landers earthquake, M = 7.28
400 to 450 m/s (10)
350 to 400 m/s (8)
300 to 350 m/s (34)
250 to 300 m/s (13)
200 to 250 m/s (5)
Range of V_{s30}
Sierra el Mayor earthquake, M = 7.2
400 to 450 m/s (27)
350 to 400 m/s (32)
300 to 350 m/s (46)
250 to 300 m/s (56)
200 to 250 m/s (22)
Range of V_{s30}
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)
PGA (g)
0.1
0.01
0.1
1
10
100
Closest distance (km)

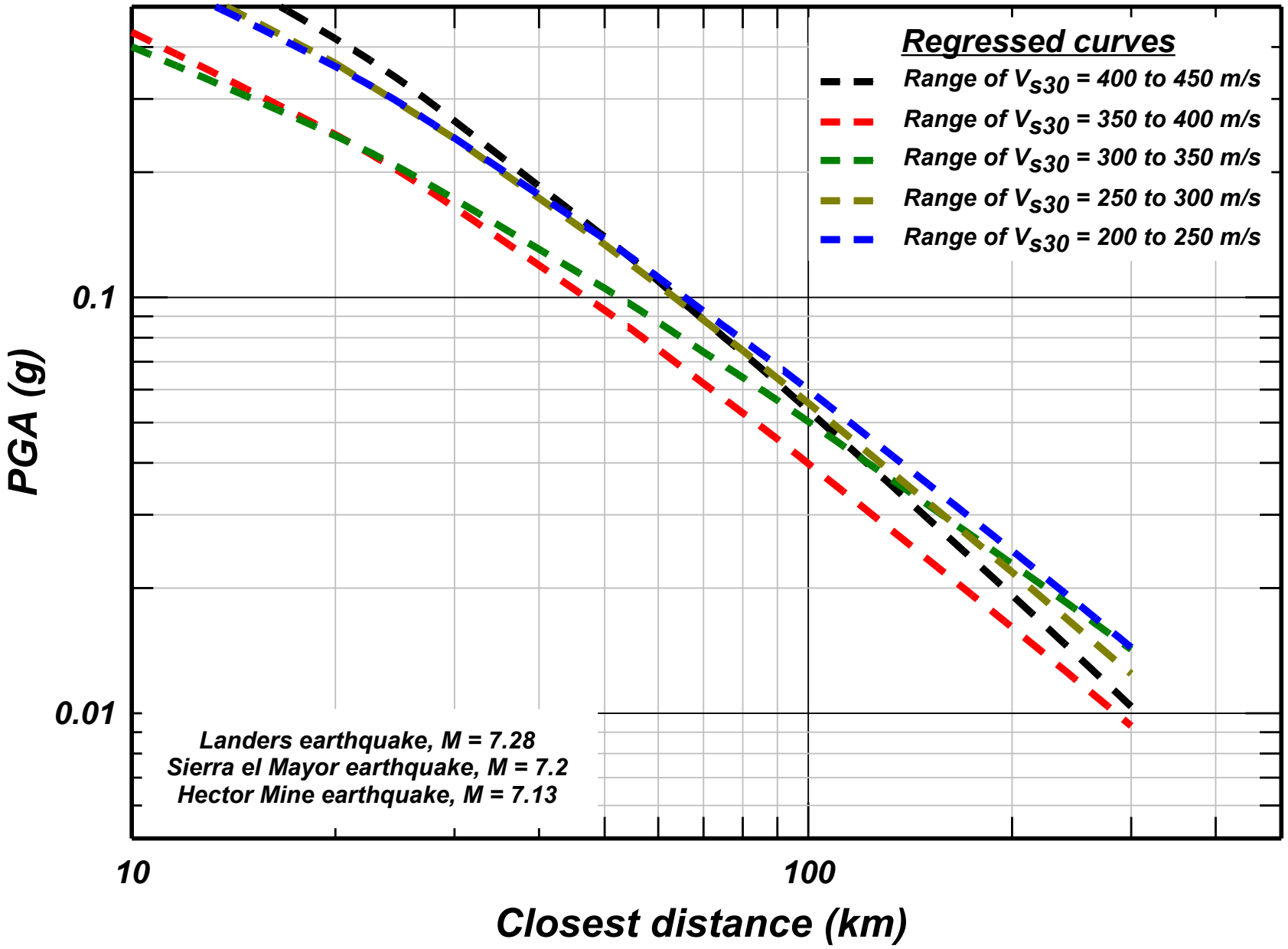

Recorded values at sites with range of V_{s30} = 400 to 450 m/s
Regressed curve
0.1
0.01
PGA (g)
Landers earthquake, M = 7.28
Sierra el Mayor earthquake, M = 7.2
Hector Mine earthquake, M = 7.13
10
100
Closest distance (km)

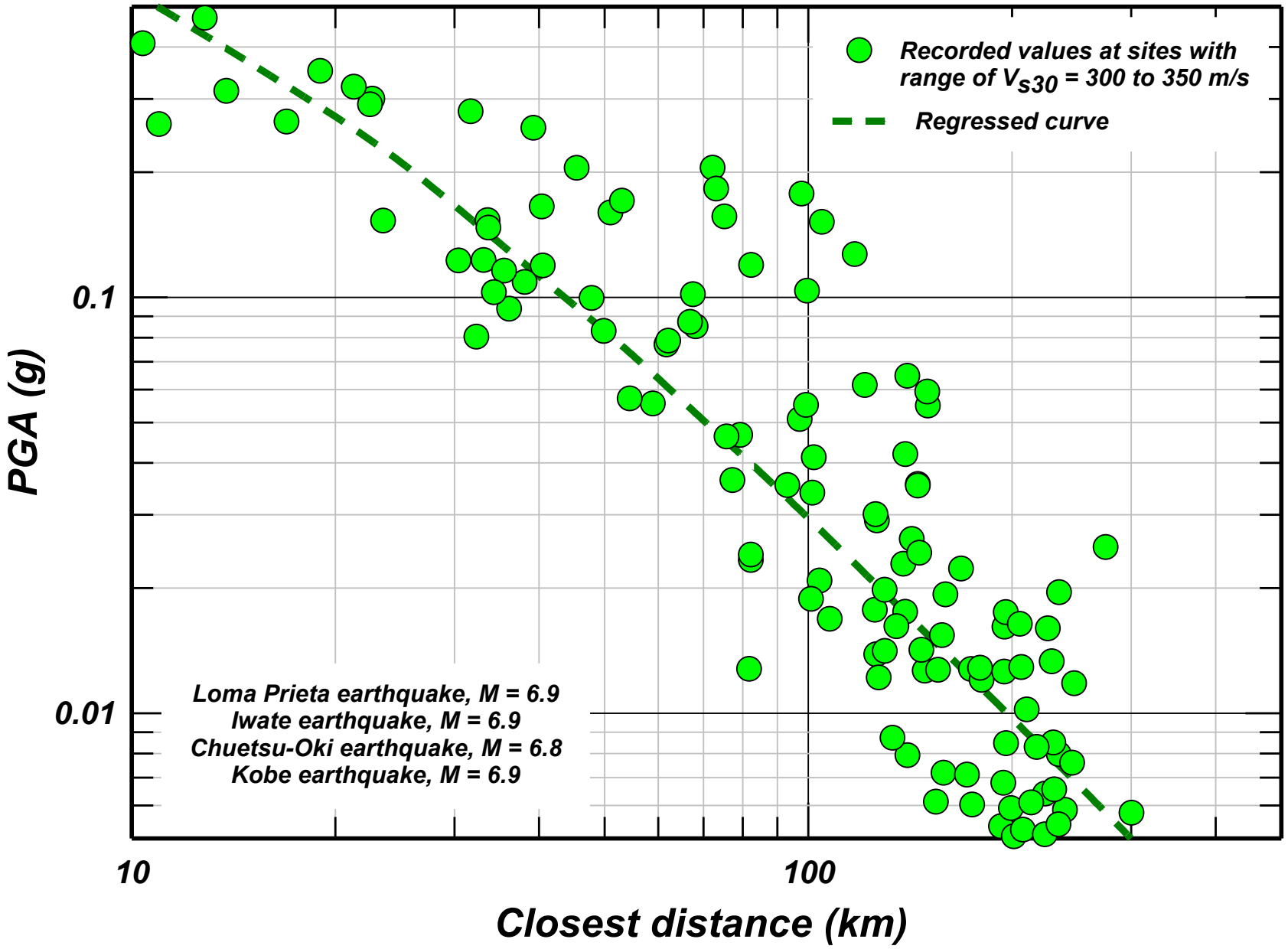

Recorded values at sites with range of V_{S30} = 350 to 400 m/s
Regressed curve
Landers earthquake, M = 7.28
Sierra el Mayor earthquake, M = 7.2
Hector Mine earthquake, M = 7.13
PGA (g)
0.1
0.01
10
100
Closest distance (km)

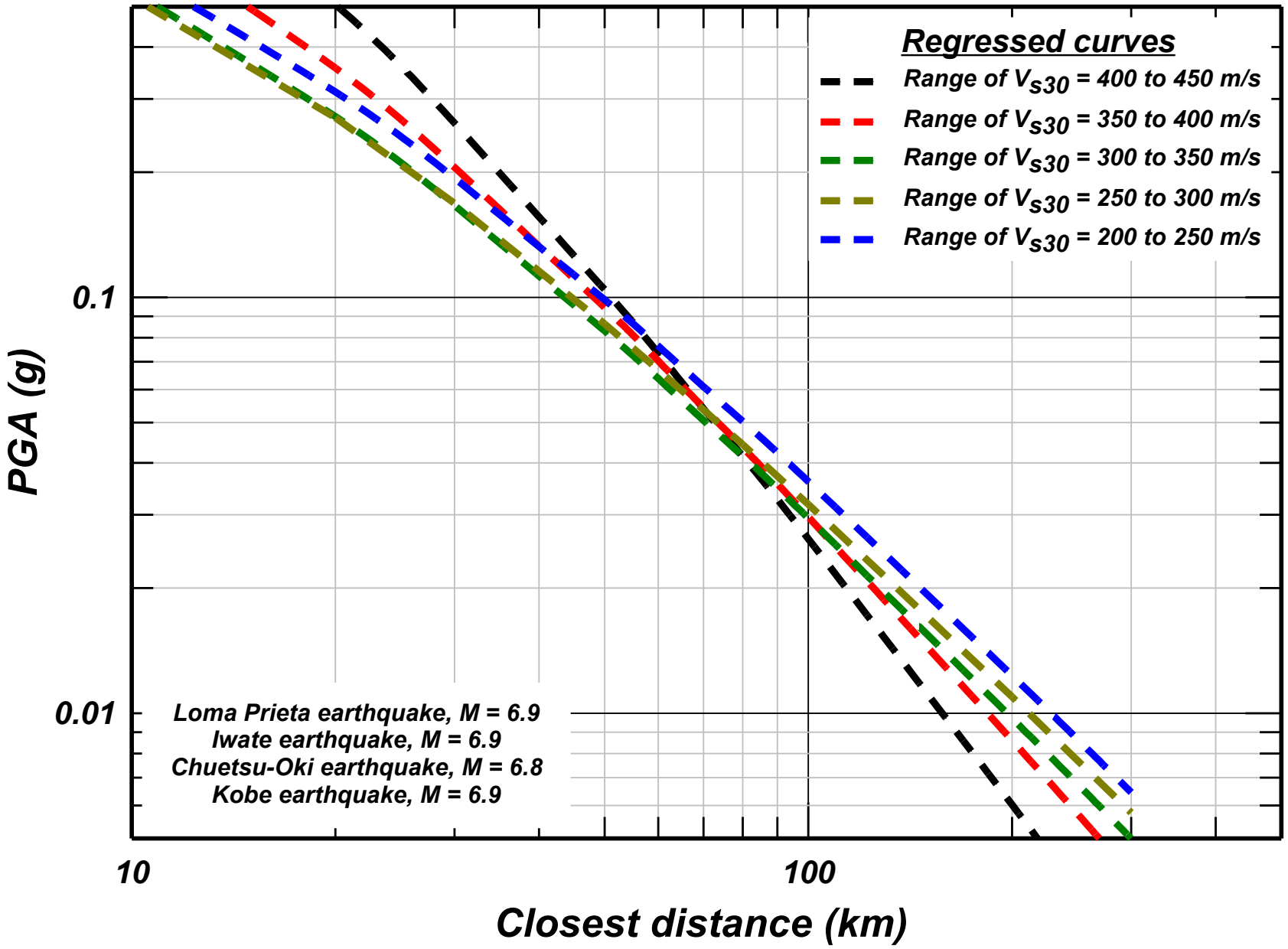

Recorded values at sites with range of V_{s30} = 300 to 350 m/s
Regressed curve
Landers earthquake, M = 7.28
Sierra el Mayor earthquake, M = 7.2
Hector Mine earthquake, M = 7.13
PGA (g)
0.1
0.01
10
100
Closest distance (km)


Recorded values at sites with range of V_{s30} = 250 to 300 m/s
Regressed curve
Landers earthquake, M = 7.28
Sierra el Mayor earthquake, M = 7.2
Hector Mine earthquake, M = 7.13
PGA (g)
0.1
0.01
10
100
Closest distance (km)


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)
0.1
0.01
10
100
Closest distance (km)


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
Landers earthquake, M = 7.28
Sierra el Mayor earthquake, M = 7.2
Hector Mine earthquake, M = 7.13
PGA (g)
0.1
0.01
10
100
Closest distance (km)

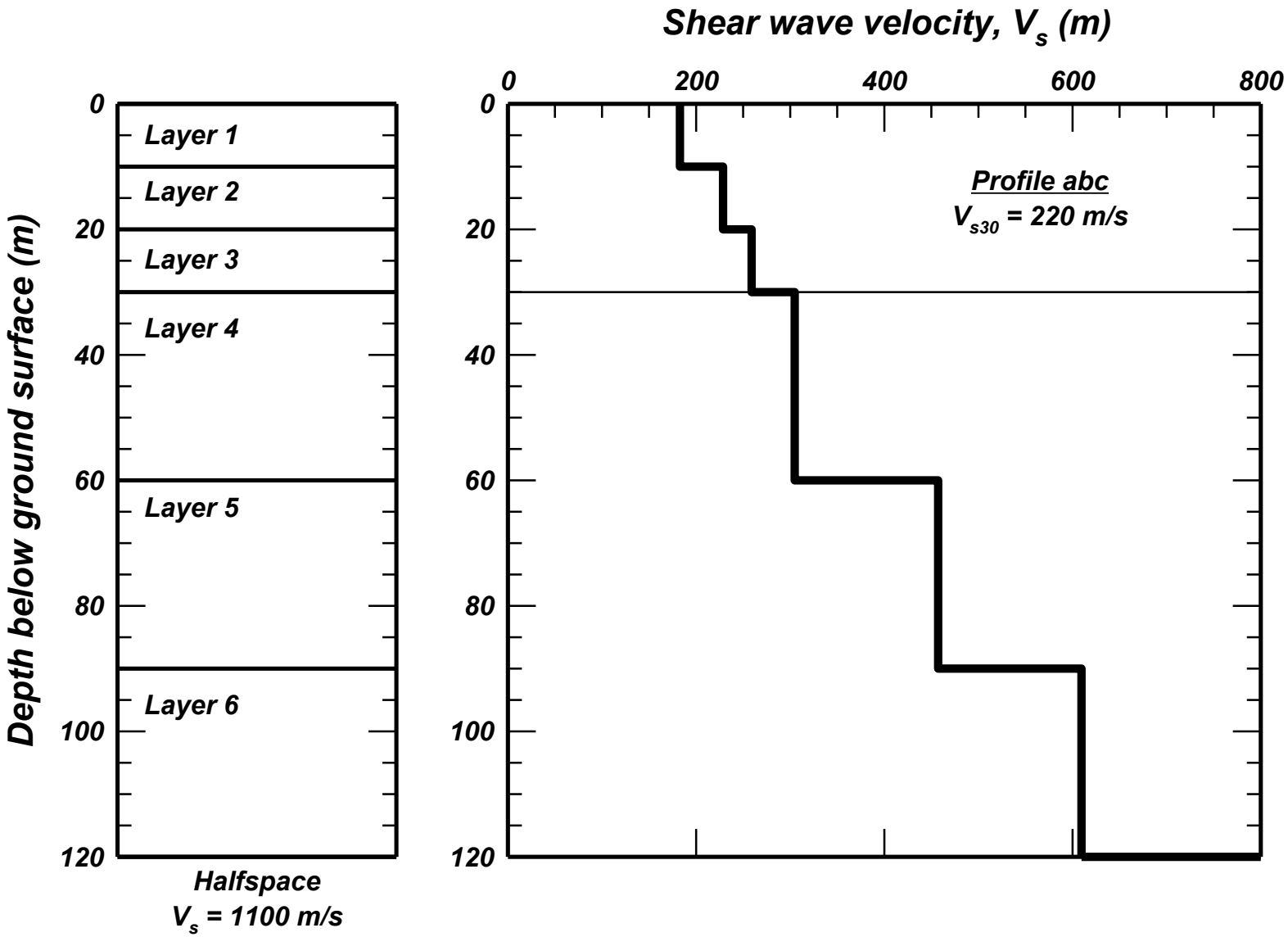

Recorded values at sites with range of V_{s30} = 300 to 350 m/s
Regressed curve
Loma Prieta earthquake, M = 6.9
Iwate earthquake, M = 6.9
Chuetsu-Oki earthquake, M = 6.8
Kobe earthquake, M = 6.9
PGA (g)
0.1
0.01
10
100
Closest distance (km)


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
Loma Prieta earthquake, M = 6.9
Iwate earthquake, M = 6.9
Chuetsu-Oki earthquake, M = 6.8
Kobe earthquake, M = 6.9
PGA (g)
0.1
0.01
10
100
Closest distance (km)

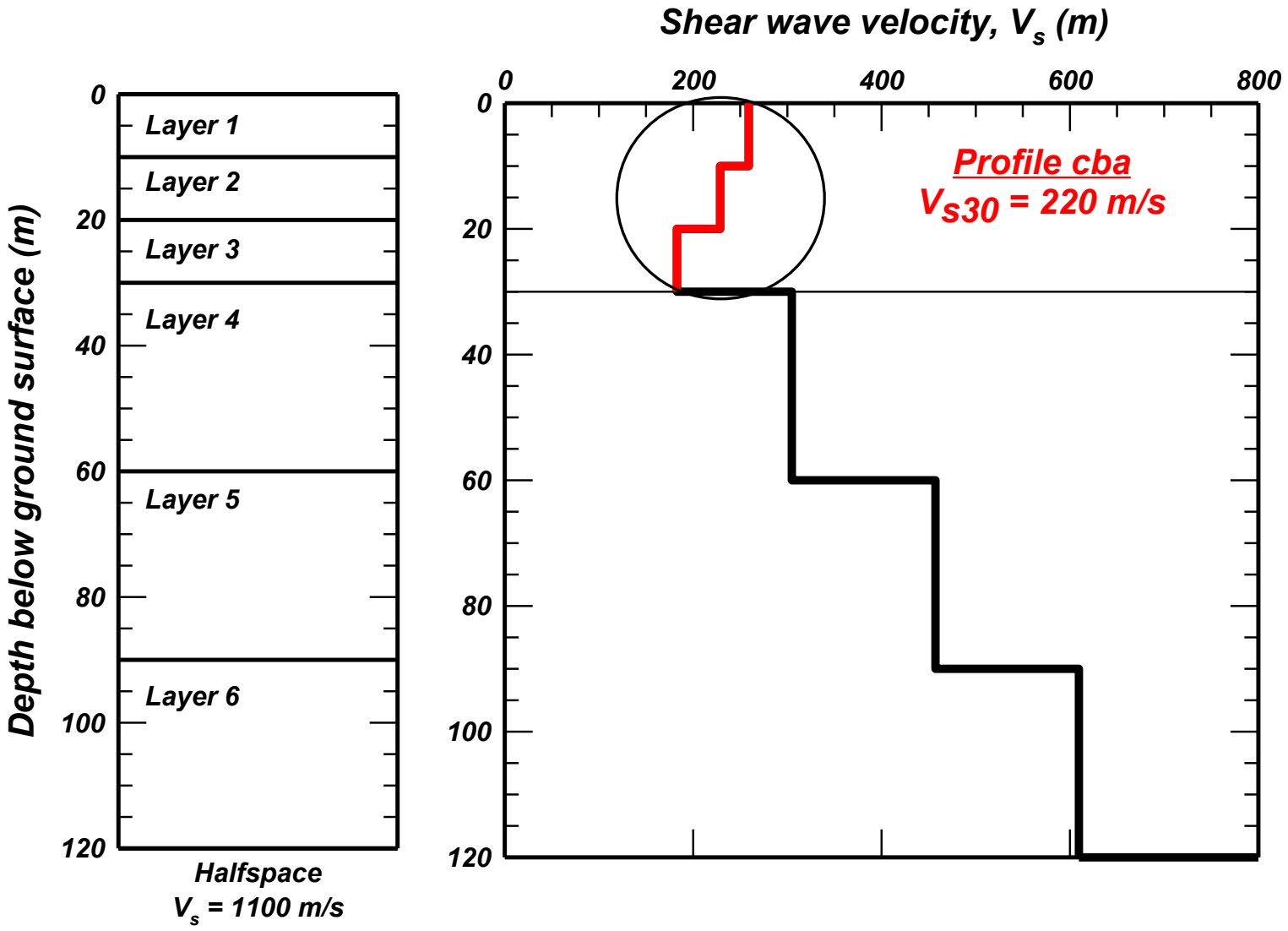
WHAT DO THE NGA DATA SHOW?

The data generally do not fully support the "published" trends.

Site Response Studies


Shear wave velocity, V_s (m)
0
200
400
600
800
Depth below ground surface (m)
0
20
40
60
80
100
120
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Halfspace
V_s = 1100 m/s
Profile abc
V_{s30} = 220 m/s

Profile abc


Shear wave velocity, V_s (m)
0
200
400
600
800
0
20
40
60
80
100
120
Depth below ground surface (m)
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Halfspace
V_s = 1100 m/s
Profile cba
V_{S30} = 220 m/s

CONCLUDING REMARKS

- ✓ ***V_{s30} is not a fundamental geotechnical parameter***
- ✓ ***V_{s30} is not a unique geotechnical parameter***
- ✓ ***Since G/G_{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 km/s or to V_s = 2.5 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