Verification of Engineering Seismology Toolbox Processed Accelerograms: 2005 Riviere du Loup, Quebec earthquake

Karen Assatourians and Gail M. Atkinson, University of Western Ontario

Feb. 2010

Introduction

The Engineering Seismology Toolbox (www.seismotoolbox.ca) is a virtual laboratory, funded by the Canada Foundation for Innovation (CFI), which compiles Engineering Seismology resources for Canada. Among these resources is a database of processed time histories for moderate earthquakes recorded on seismographic stations across Canada. Records were downloaded from the Canadian National Seismic Network (CNSN) and POLARIS stations from the Geological Survey of Canada, using their autodrm facility. The records were processed and filtered as described on the Toolbox website, and a variety of products is made available to users, including corrected time series, Fourier spectra, and response spectra. The data processing procedures were checked by comparison against a number of standard programs, as described on the website. Figure 1 shows the area covered in the "West", "East" and "North" databases; the "North" database includes all records north of 52N, while the "West" and "East" datasets are southern Canada west and east of 110W, respectively. Figure 2 provides a plot of the distribution of data in magnitude-distance space for each region; records for the west are only included to 300 km, while eastern records are compiled to larger distances due to the lesser eastern attenuation.

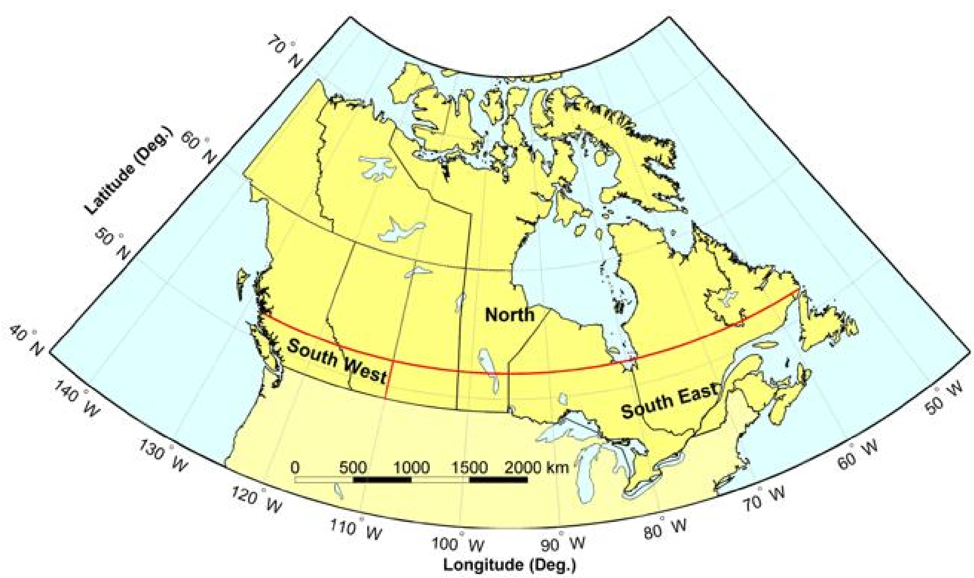


Figure 1 – Subdivision of dataset regions for the Engineering Seismology Toolbox records

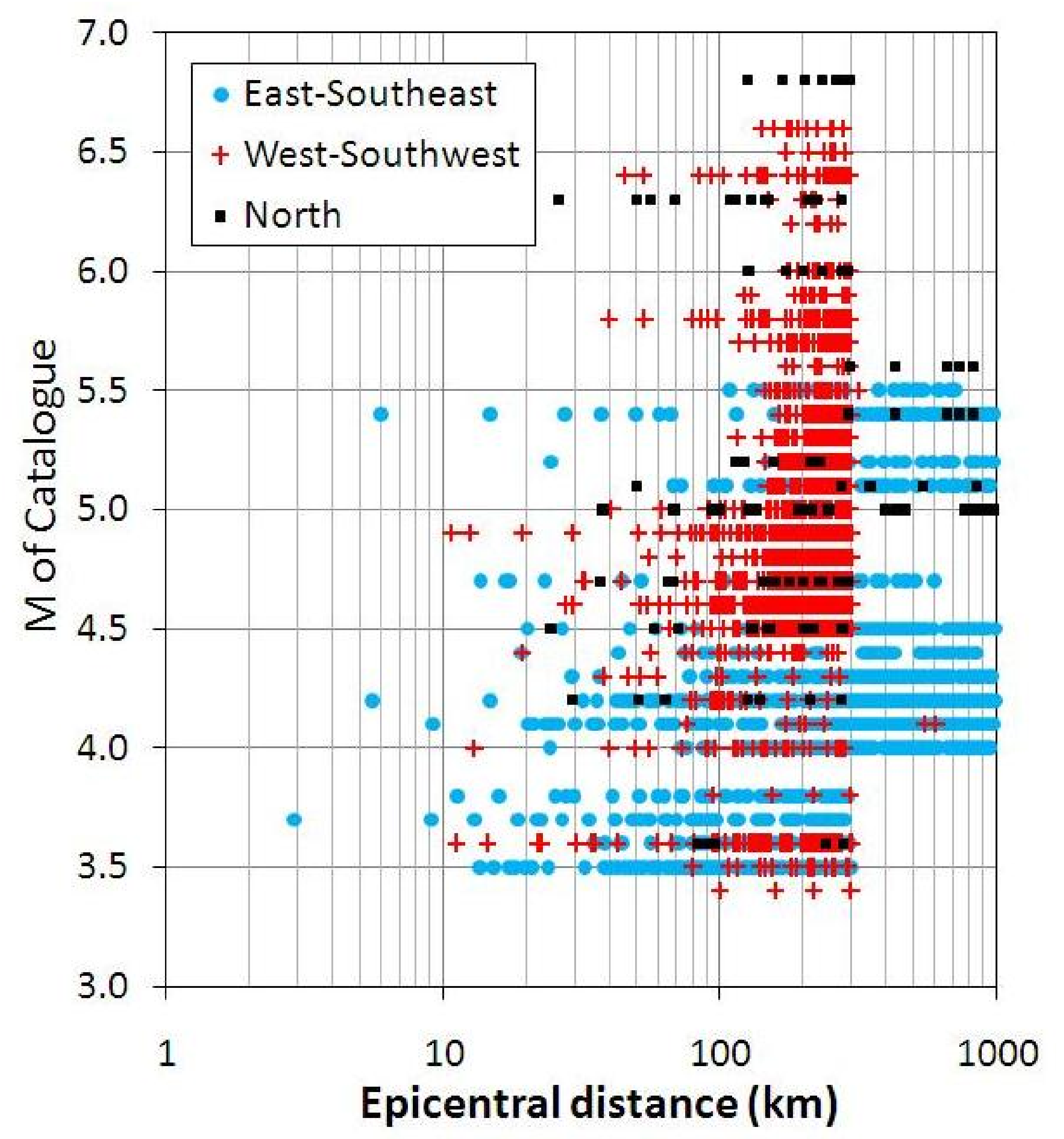


Figure 2 – Magnitude-distance distribution of processed seismograms in the Engineering Seismology Toolbox database.

Comparison of seismographic records to strong-motion records: MN5.4 2005 Riviere du Loup, Quebec earthquake

The Geological Survey of Canada has recently released digitized strong-motion records from the MN5.4 2005 Riviere du Loup, Quebec earthquake (Lin and Adams, 2010: GSC Open-file report "Strong motion records of the Riviere-du-Loup, Quebec earthquake of March 6, 2005). Several of these strong-motion records are co-located with broadband seismographic records that were processed by the Engineering Seismology Toolbox software package (program ICORRECT). This provides a good opportunity to compare the corrected accelerograms and response spectra from the seismograms with those from strong-motion instruments. It has been previously acknowledged that at least one of the seismographic records clipped and is unreliable (A21); however other investigators have raised concerns over a number of the other records, and whether light clipping may have affected the published response spectra from these records (C. Cramer, pers. comm., 2008, 2009).

In the Appendix, we graphically compare the corrected accelerograms and response spectra for co-located seismographic stations (processed with ICORRECT) with the strong-motion data from the GSC. It is clear that the records agree well for most stations, with some minor differences at long periods, probably attributable to slightly-different filtering choices.

For the clipped station, A21, there are clear discrepancies. It is noted that the problems with A21 are apparent from plotting the raw velocity records (digital counts), and that these problems cannot be remediated by processing.

One other problem is noted: the north component of A61 has long-period problems, which make the response spectra unreliable for frequencies <1 Hz. This problem has also been noted by the GSC (Lan Linn, pers. comm.). The problem is clear in the raw velocity trace. This particular problem may be remediated by low-cut filtering the time series at 0.5 sec, as shown in the plots. After filtering, A61 N has a reasonable velocity trace, and the response spectrum is reliable for frequencies above the high-pass filter (ie. f>1 Hz).

Our conclusion is that the seismographic and strong-motion data produce very similar corrected accelerograms and response spectra. For the few cases where there are problems with the seismographic records, these are apparent from inspection of the raw or corrected velocity trace. This points to the importance of visually inspecting the velocity trace of corrected seismograms to verify records. Such verification will be conducted for the records of every event of M>4.5 in the Toolbox. For the many thousands of small-event records, such detailed verification is not generally practical (too time consuming). Instead, it is recommended to perform an overall amplitude-based screening of such records to discard those that fall more than a reasonable number of standard deviations from the expected values for a given magnitude and distance; such anomalous records are more likely to reflect data errors than actual observations.

Observations of Attenuation from Riviere-du-Loup response spectra

Figure 3 compares horizontal-component 5% damped response spectra (PSA, pseudo-acceleration) with the ground-motion prediction equations (GMPEs) of Atkinson and Boore (2006, BSSA), for moment magnitude **M**4.5, 5.0 and 5.5 (both horizontal components are plotted). For these plots it is assumed that the closest distance to the fault is equal to the hypocentral distance; the focal depth is taken as 13 km. NEHRP site classes are distinguished in most cases based on the general classification of a site as “bedrock” (NEHRP A) or “soil” (NEHRP D). Shear-wave velocities are available only for a limited number of sites, none of which are within 100 km of the source, making the actual site conditions of the recording sites a matter of considerable uncertainty. The H/V ratio is often used as a rough proxy for site amplification. It is therefore interesting to also plot the vertical-component ground motions against the AB06 GMPEs, as shown on Figure 4. On both Figures 3 and 4, a fitted line (log PSA vs. log Rhypo) for the rock data at R<70 km is also plotted. The fit lines are not always stable (especially on the vertical component) due to the sparse data, but the overall trends are noteworthy.

The following observations are made from the comparison of the recorded ground motions with the AB06 GMPEs:

1. The low-frequency ground-motions are generally consistent in amplitude with the estimated moment magnitude of 4.7 for this event.
2. At high frequencies, the horizontal-component motions are significantly amplified relative to the vertical. Overall, a high-frequency magnitude (eg. as in Atkinson and Hanks, 1995) of about 5.0 would be inferred.
3. The most striking feature of the comparisons concerns the attenuation rate. The attenuation appears to be faster than AB06. In particular, at R<70 km the horizontal-component amplitudes decay faster than the $R^{-1.3}$ rate used in AB06 (apparent slopes of 1.5 to 2.0). Near-source amplitudes on the horizontal component are high relative to AB06, while distant amplitudes (>500 km) are low. For the vertical component, the AB06 near-source attenuation slope of 1.3 appears about right, though the scatter precludes definitive conclusions.

The discrepancies between the horizontal and vertical component data suggest that site response may be a significant factor in the observed large amplitudes on the horizontal component at near-source distances. Shear-wave velocity studies of the recording stations within 70 km of the source are needed to resolve this question. Another possibility is that the H/V ratio depends significantly on distance; however previous studies (eg. Atkinson, 1993; 2004 BSSA) have not found any such trends. Alternatively, the Riviere-du-Loup event may have had a high stress drop with steep attenuation.

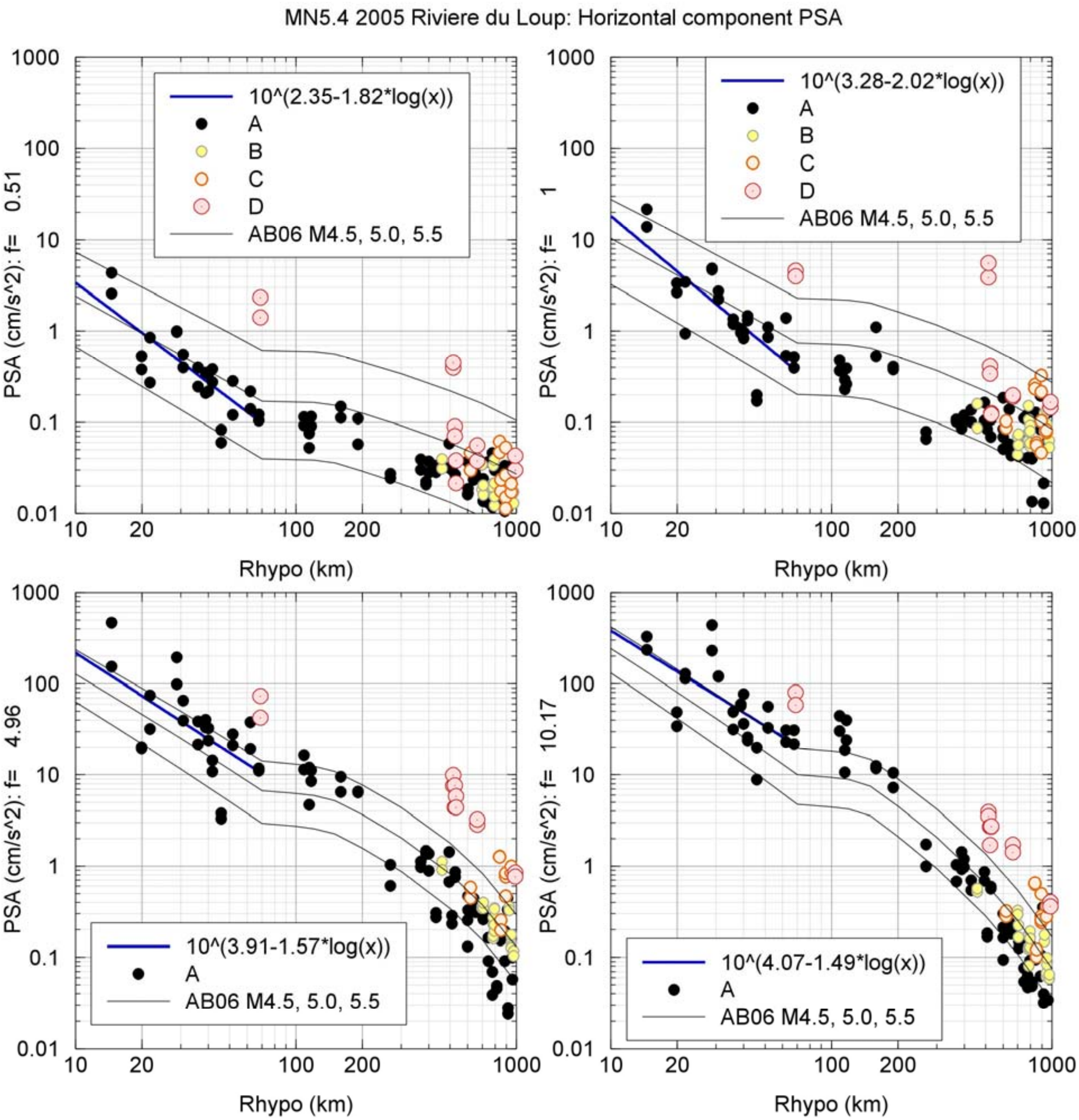


*Figure 3 – Comparison of horizontal-component response spectral ordinates with Atkinson and Boore (2006) predictions for **M** 4.5, 5.0 and 5.5.*

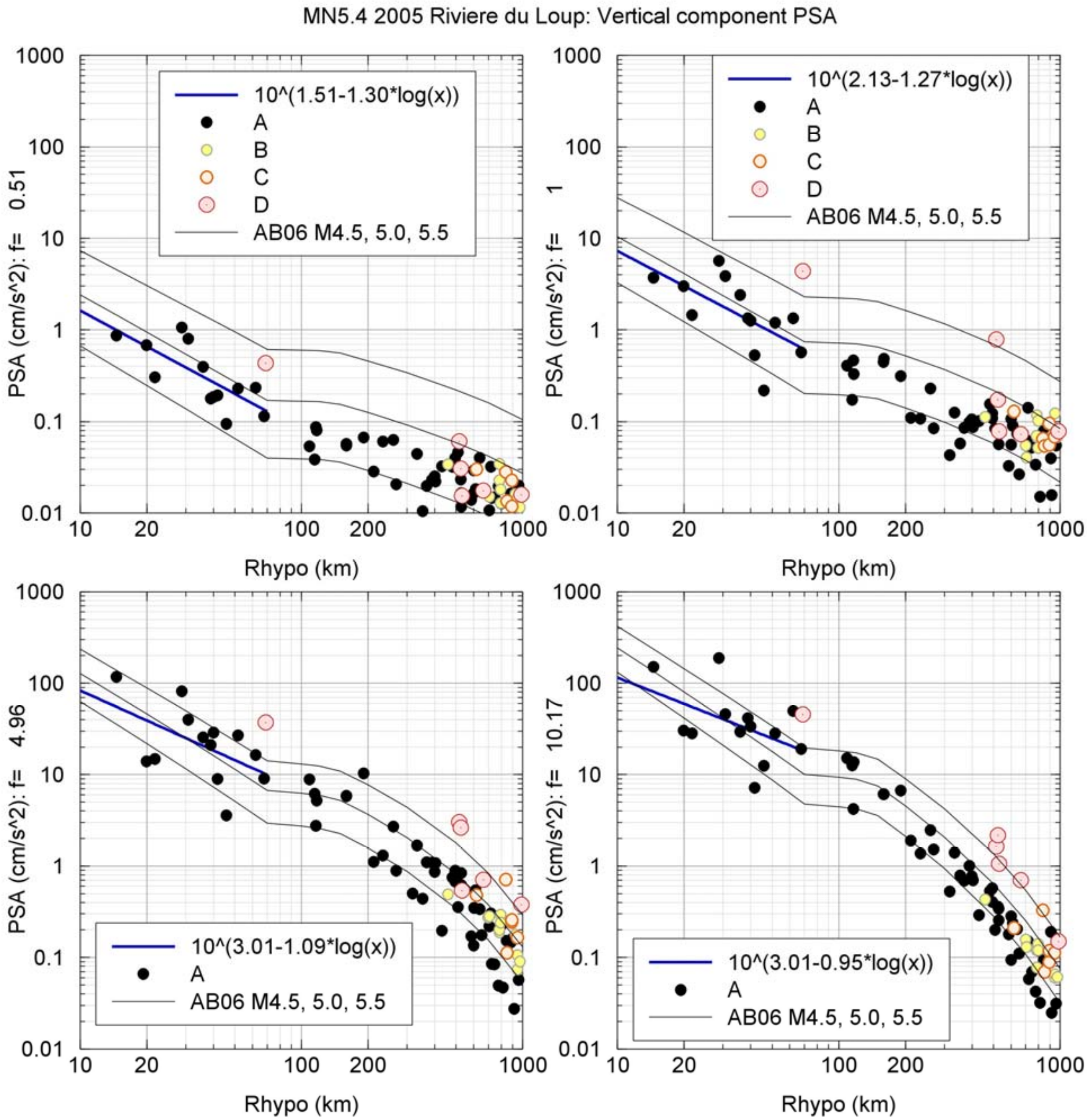
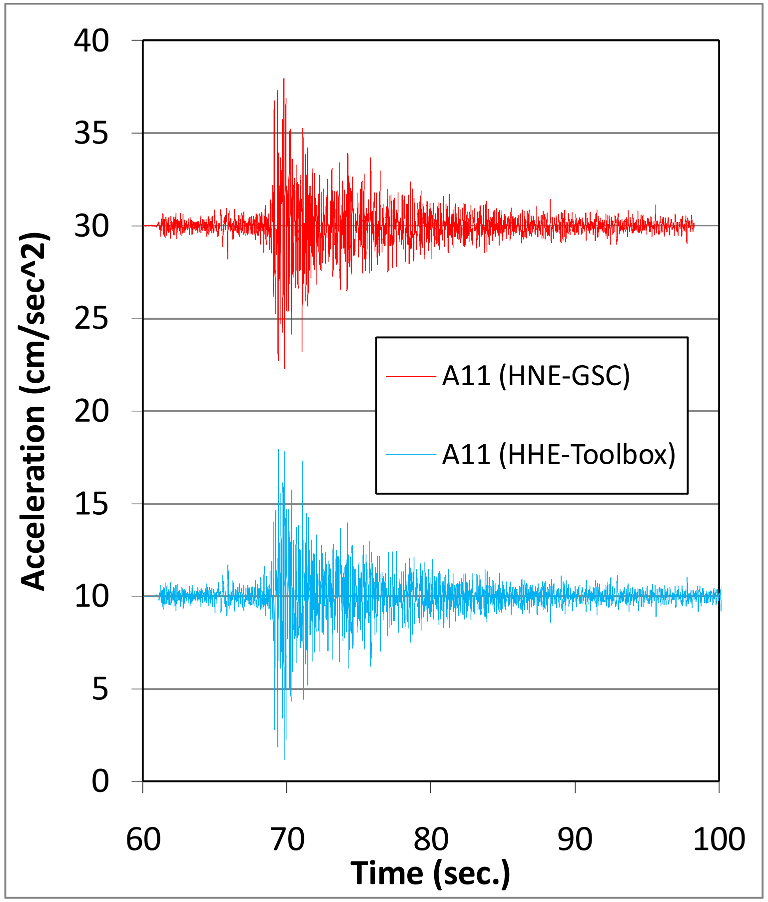
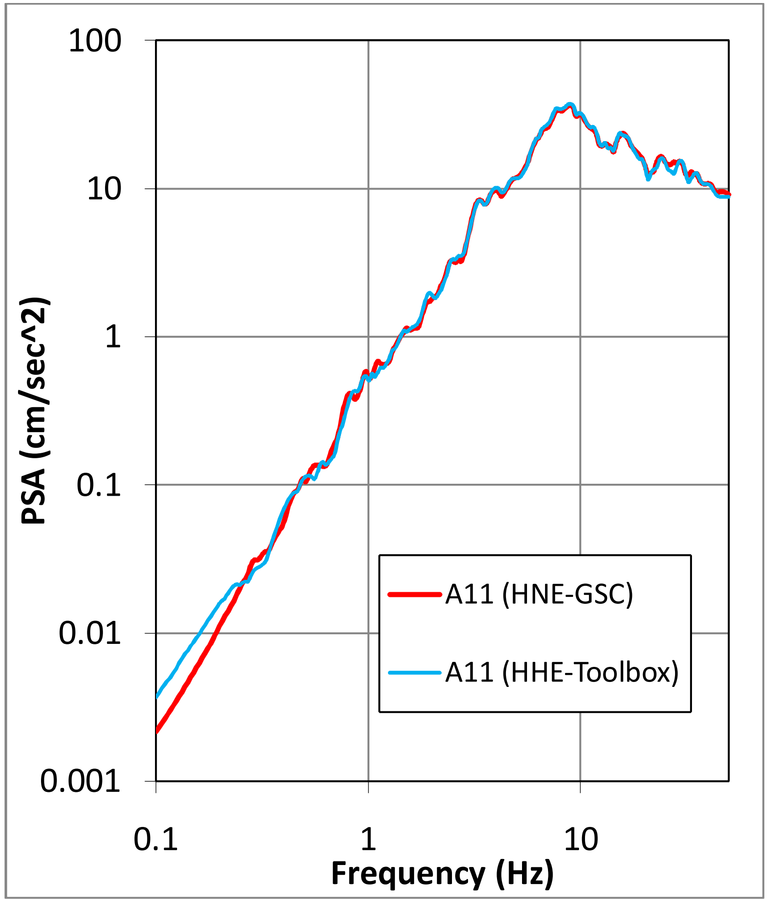
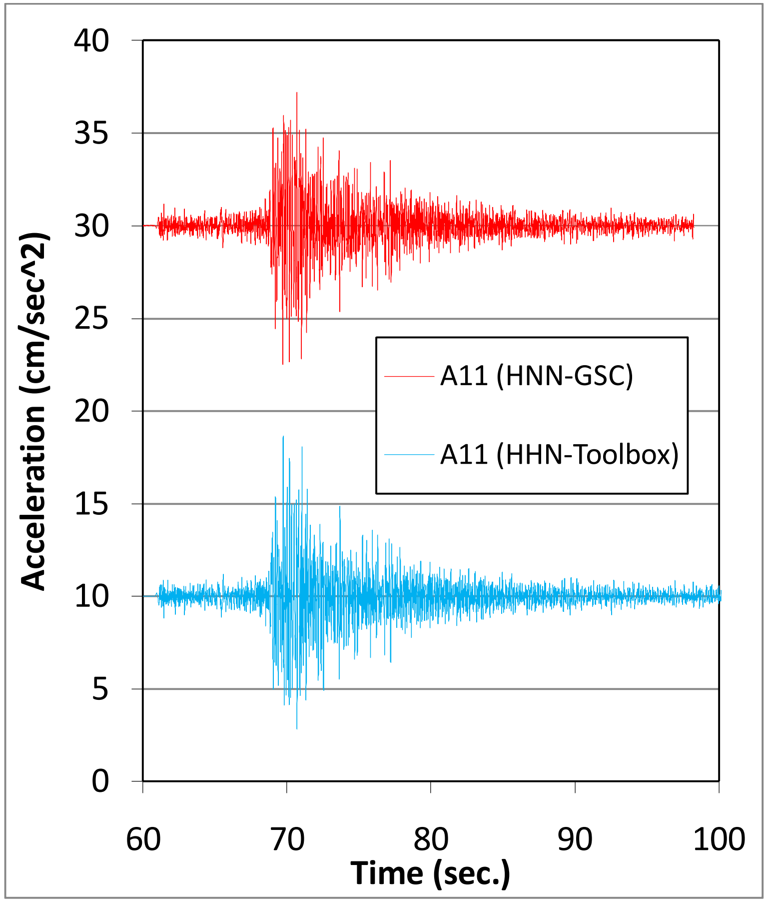


*Figure 4 – Comparison of vertical-component response spectral ordinates with Atkinson and Boore (2006) predictions for **M** 4.5, 5.0 and 5.5.*

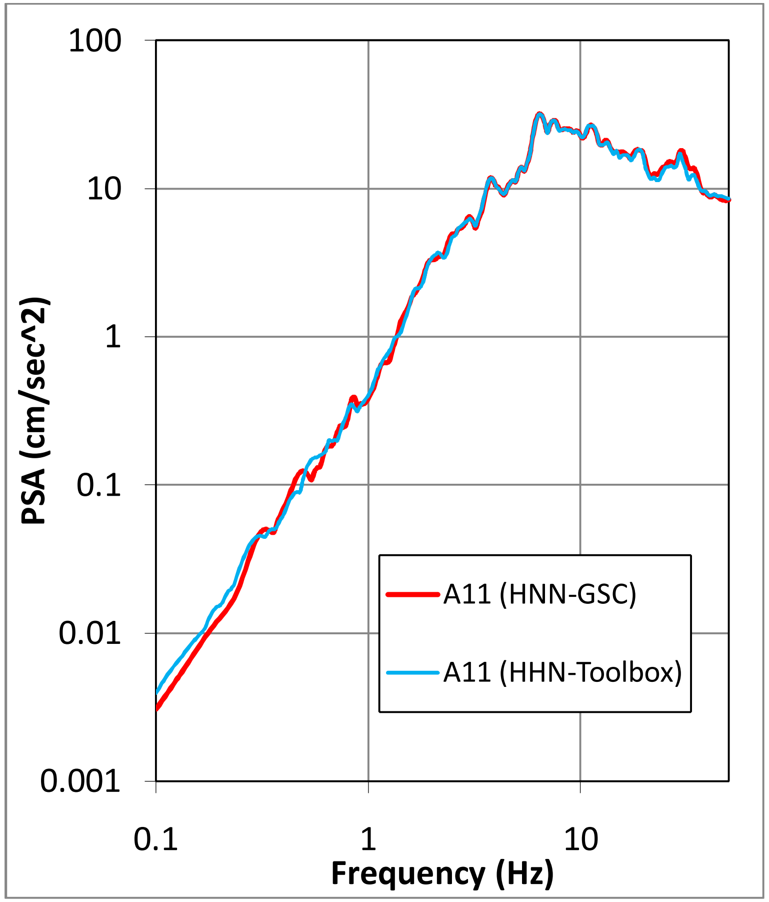
Appendix: Part A – Comparison of Toolbox corrected accelerograms and strong-motion accelerograms and response spectra. For components with significant discrepancies, the velocity records are also shown. Note that problems for these components are apparent by inspection of the velocity traces. (pages follow)


Acceleration (cm/sec^2)
40
35
30
25
20
15
10
5
0
60
70
80
90
100
Time (sec.)
A11 (HNE-GSC)
A11 (HHE-Toolbox)

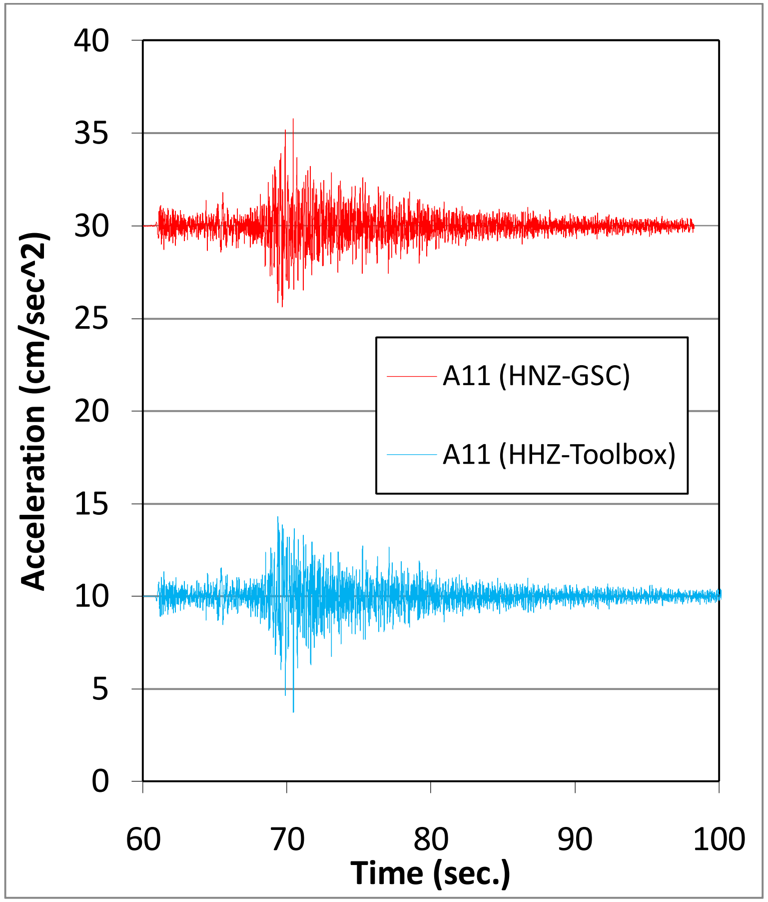

PSA (cm/sec^2)
100
10
1
0.1
0.01
0.001
0.1
1
10
Frequency (Hz)
A11 (HNE-GSC)
A11 (HHE-Toolbox)



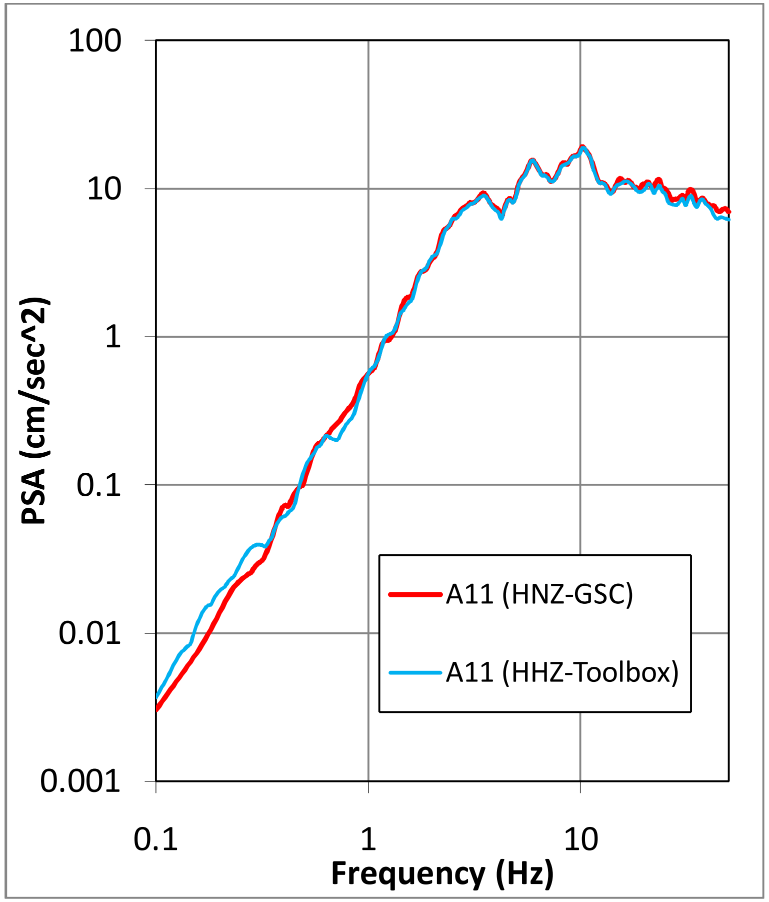
Acceleration (cm/sec^2)
40
35
30
25
20
15
10
5
0
60
70
80
90
100
Time (sec.)
A11 (HNN-GSC)
A11 (HHN-Toolbox)



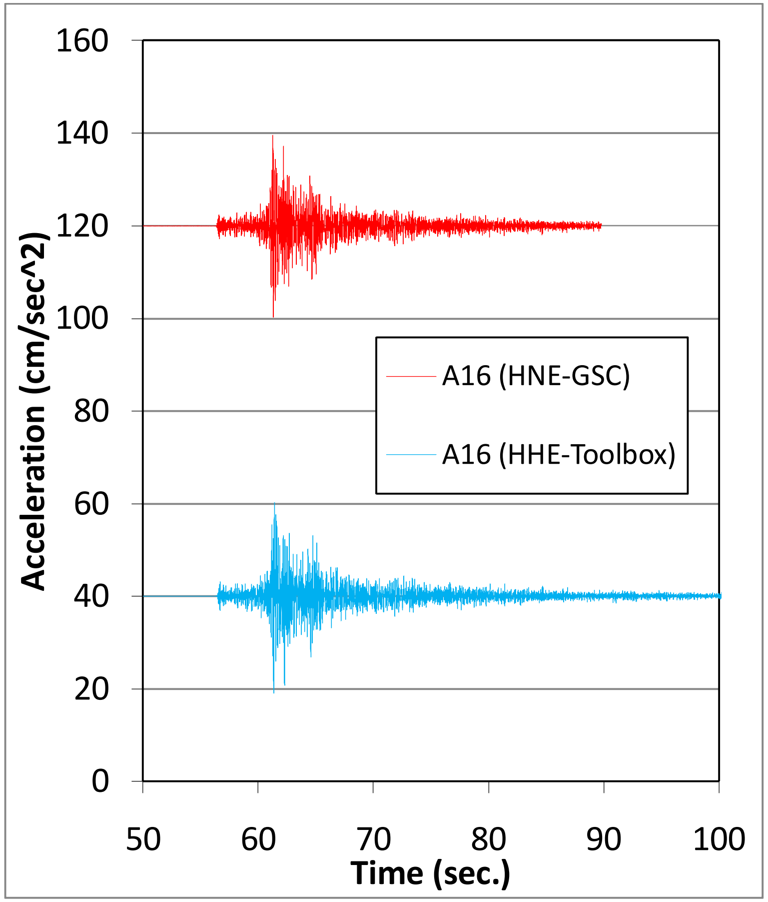
PSA (cm/sec^2)
100
10
1
0.1
0.01
0.001
0.1
1
10
Frequency (Hz)
A11 (HNN-GSC)
A11 (HHN-Toolbox)

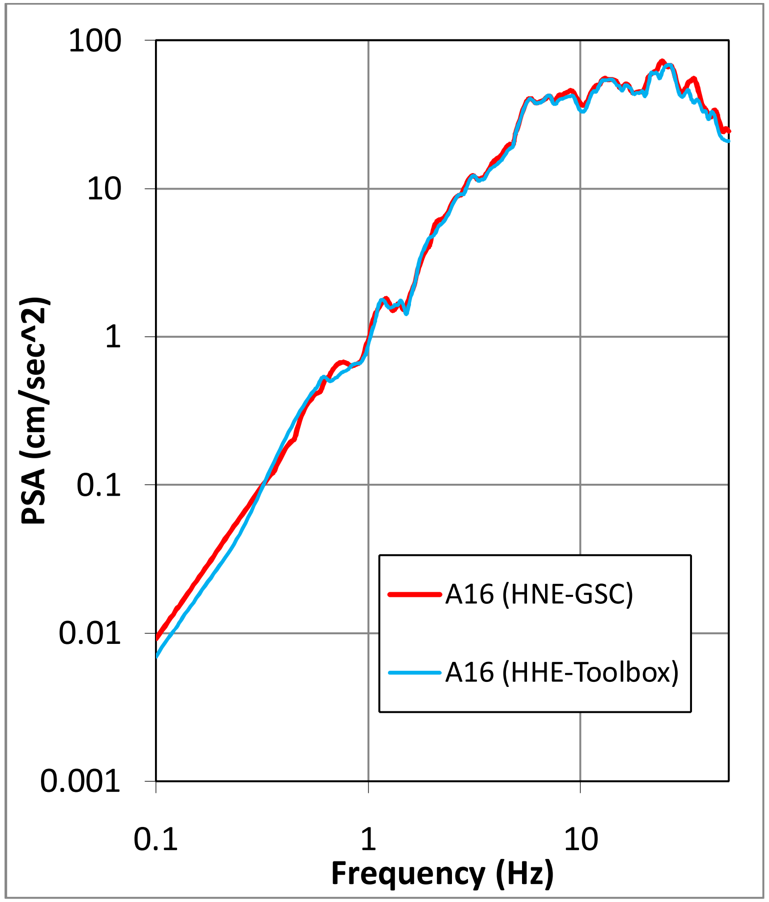


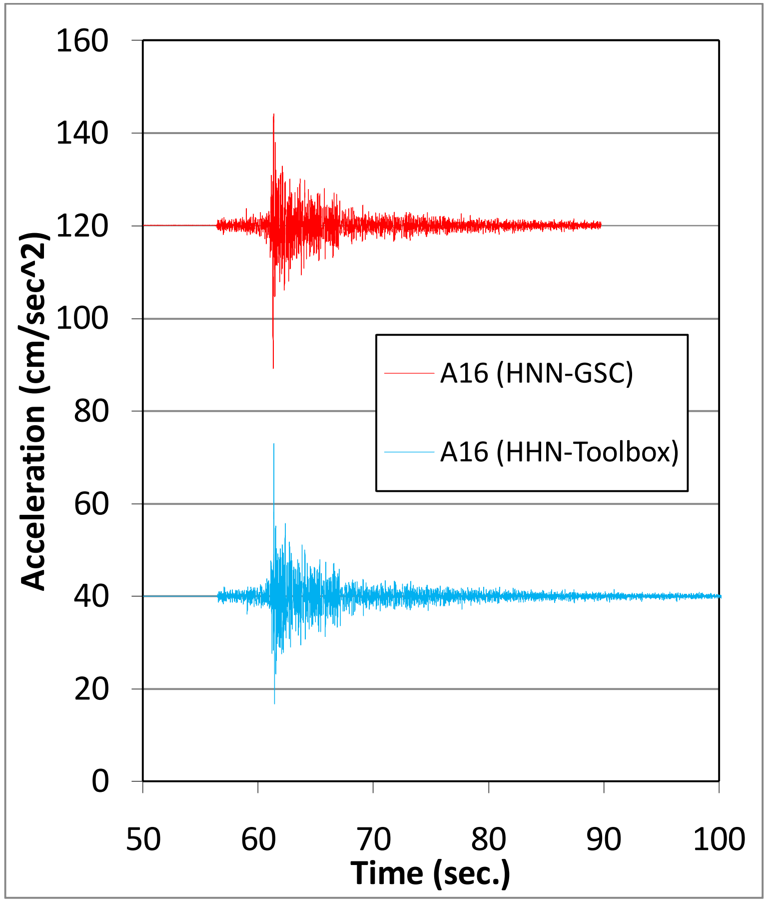
Acceleration (cm/sec^2)
40
35
30
25
20
15
10
5
0
60
70
80
90
100
Time (sec.)
A11 (HNZ-GSC)
A11 (HHZ-Toolbox)

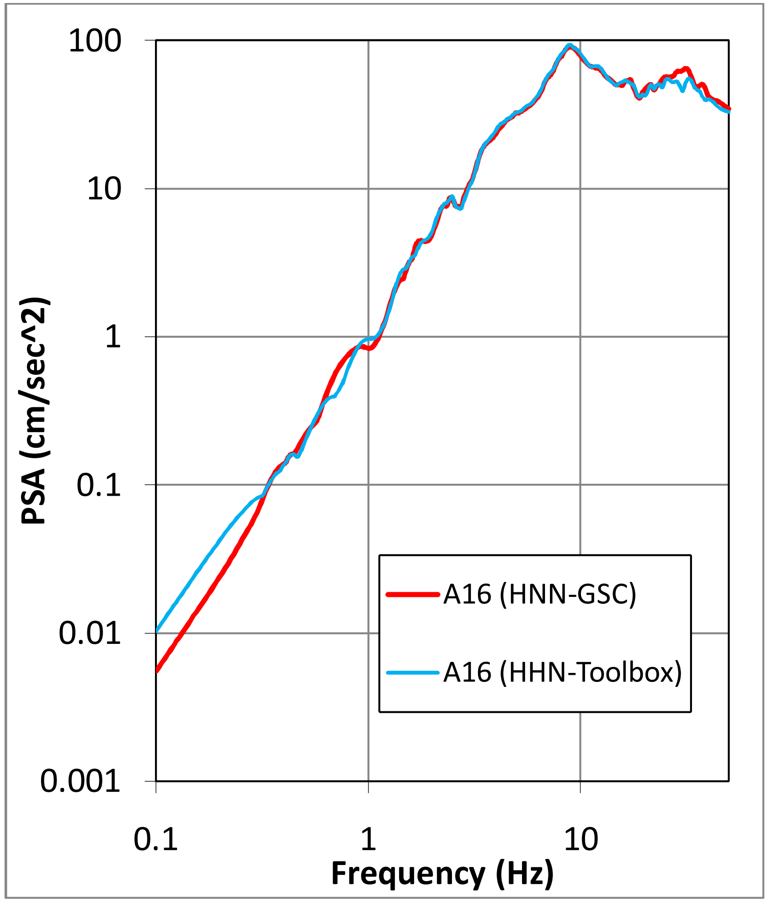


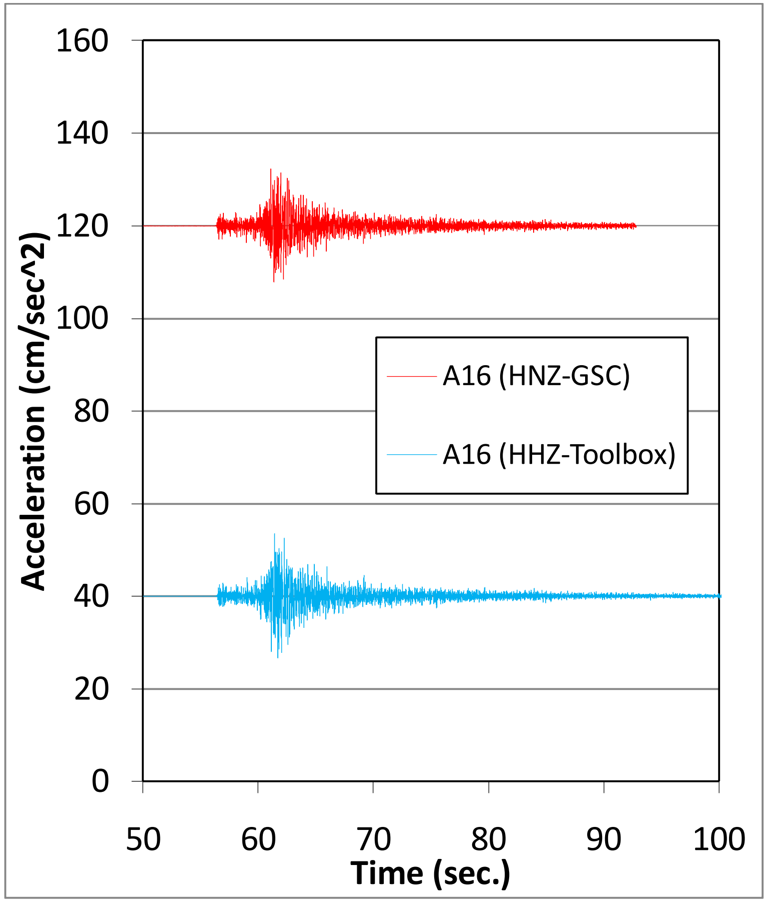
PSA (cm/sec^2)
100
10
1
0.1
0.01
0.001
0.1
1
10
Frequency (Hz)
A11 (HNZ-GSC)
A11 (HHZ-Toolbox)

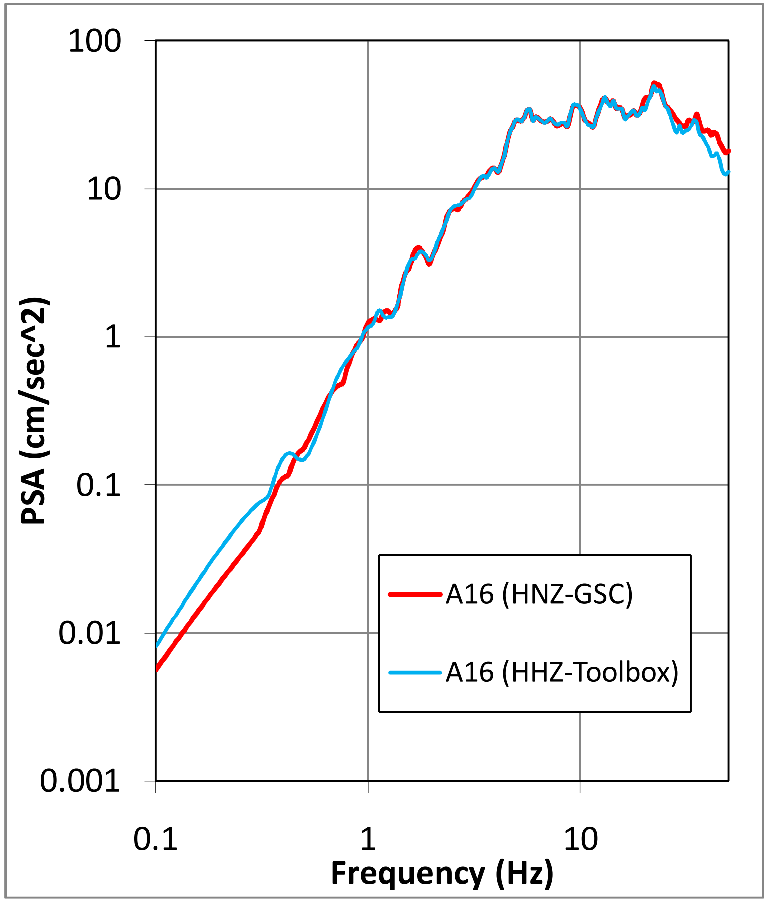

160
140
120
100
80
60
40
20
0
Acceleration (cm/sec^2)
50
60
70
80
90
100
Time (sec.)
A16 (HNE-GSC)
A16 (HHE-Toolbox)

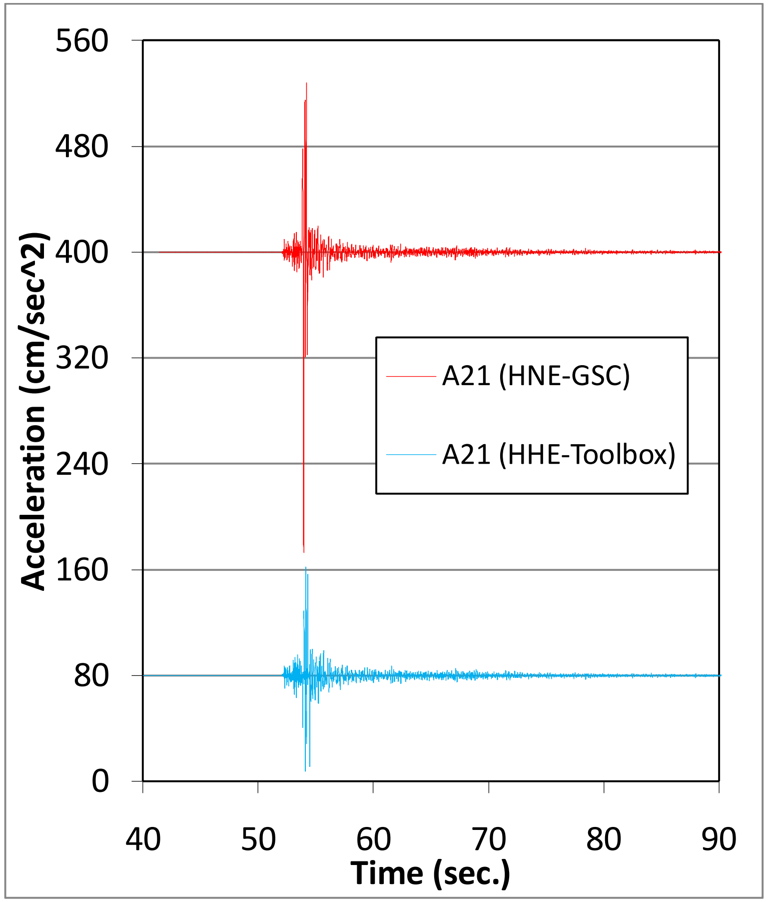

100
10
1
0.1
0.01
0.001
PSA (cm/sec^2)
0.1
1
10
Frequency (Hz)
A16 (HNE-GSC)
A16 (HHE-Toolbox)

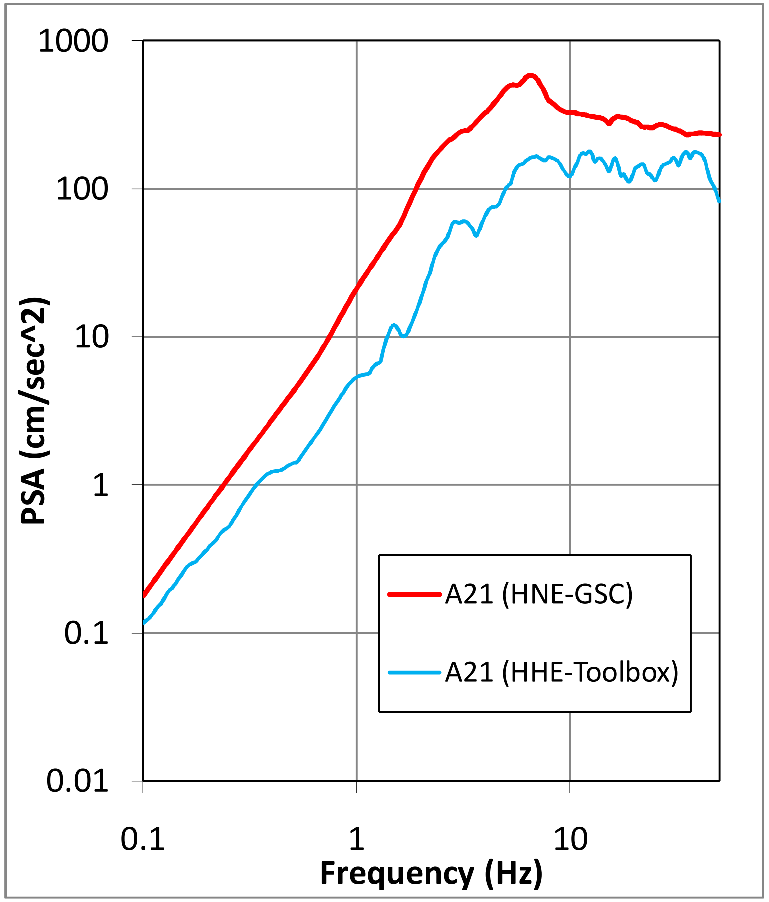

160
140
120
100
80
60
40
20
0
Acceleration (cm/sec^2)
50
60
70
80
90
100
Time (sec.)
A16 (HNN-GSC)
A16 (HHN-Toolbox)

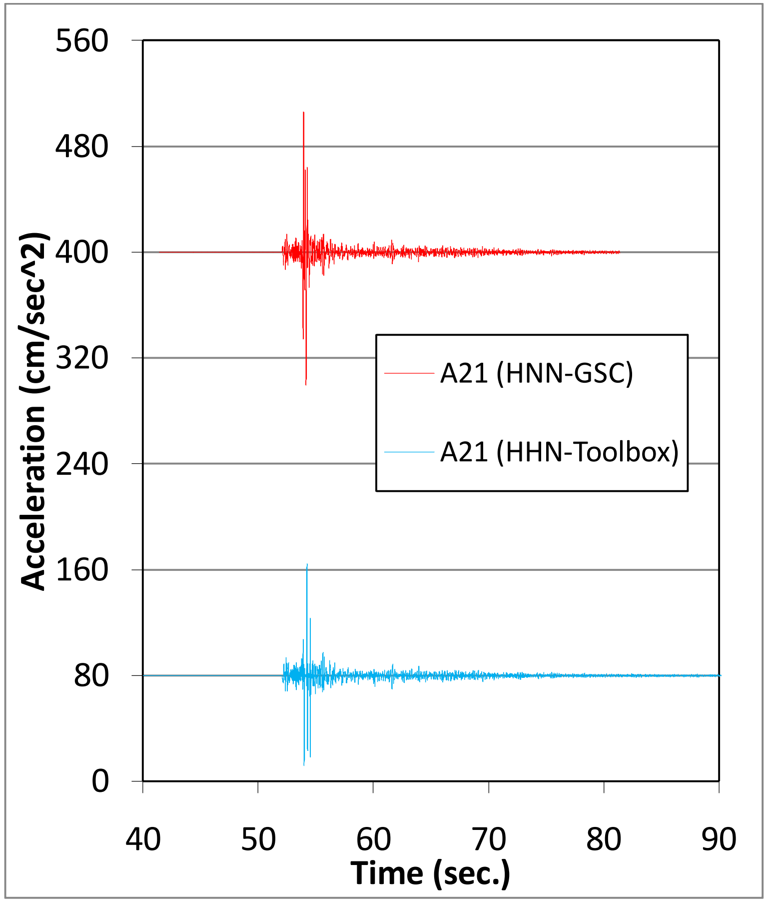

100
10
1
0.1
0.01
0.001
PSA (cm/sec^2)
0.1
1
10
Frequency (Hz)
A16 (HNN-GSC)
A16 (HHN-Toolbox)


160
140
120
100
80
60
40
20
0
50
60
70
80
90
100
Time (sec.)
Acceleration (cm/sec^2)
A16 (HNZ-GSC)
A16 (HHZ-Toolbox)

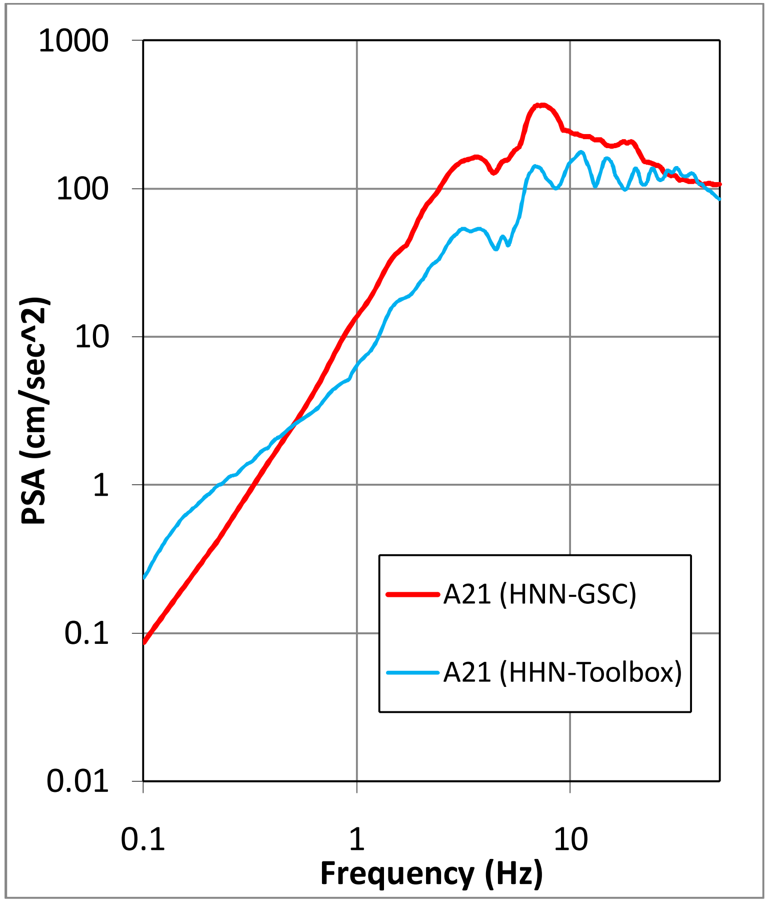

100
10
1
0.1
0.01
0.001
0.1
1
10
Frequency (Hz)
PSA (cm/sec^2)
A16 (HNZ-GSC)
A16 (HHZ-Toolbox)


560
480
400
320
240
160
80
0
40
50
60
70
80
90
Acceleration (cm/sec^2)
Time (sec.)
A21 (HNE-GSC)
A21 (HHE-Toolbox)

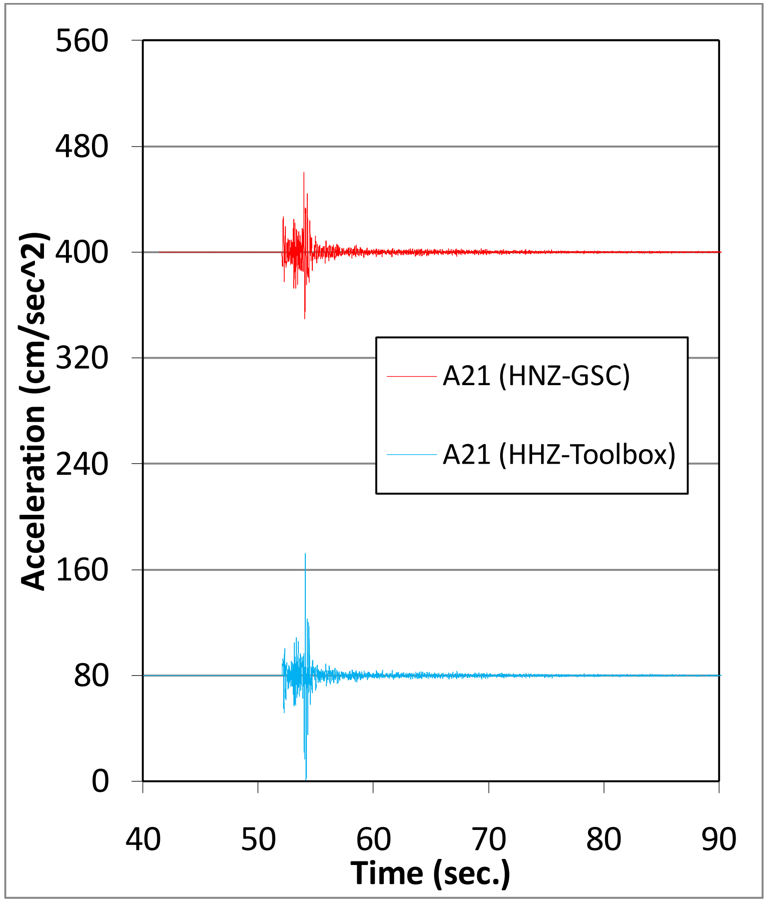

1000
100
10
1
0.1
0.01
0.1
1
10
PSA (cm/sec^2)
Frequency (Hz)
A21 (HNE-GSC)
A21 (HHE-Toolbox)

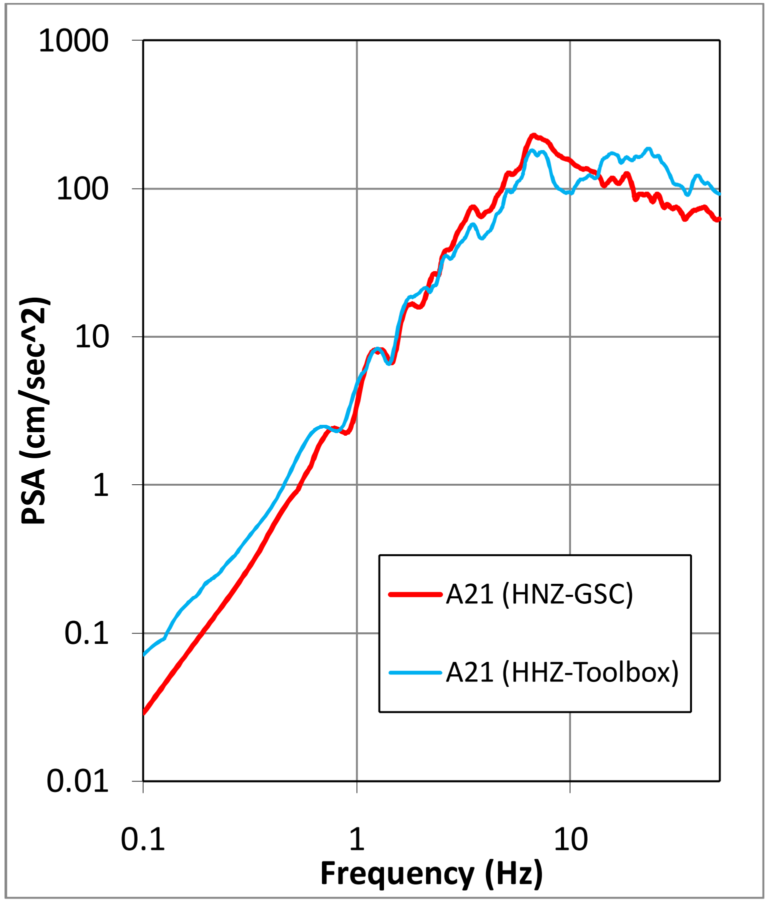


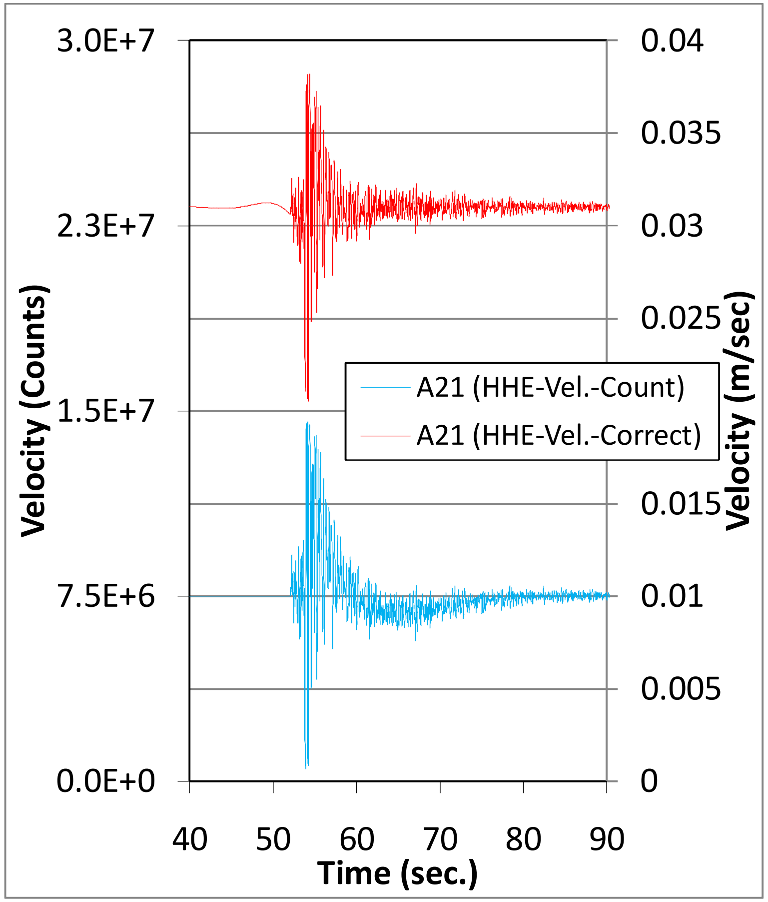
560
480
400
320
240
160
80
0
Acceleration (cm/sec^2)
40
50
60
70
80
90
Time (sec.)
A21 (HNN-GSC)
A21 (HHN-Toolbox)

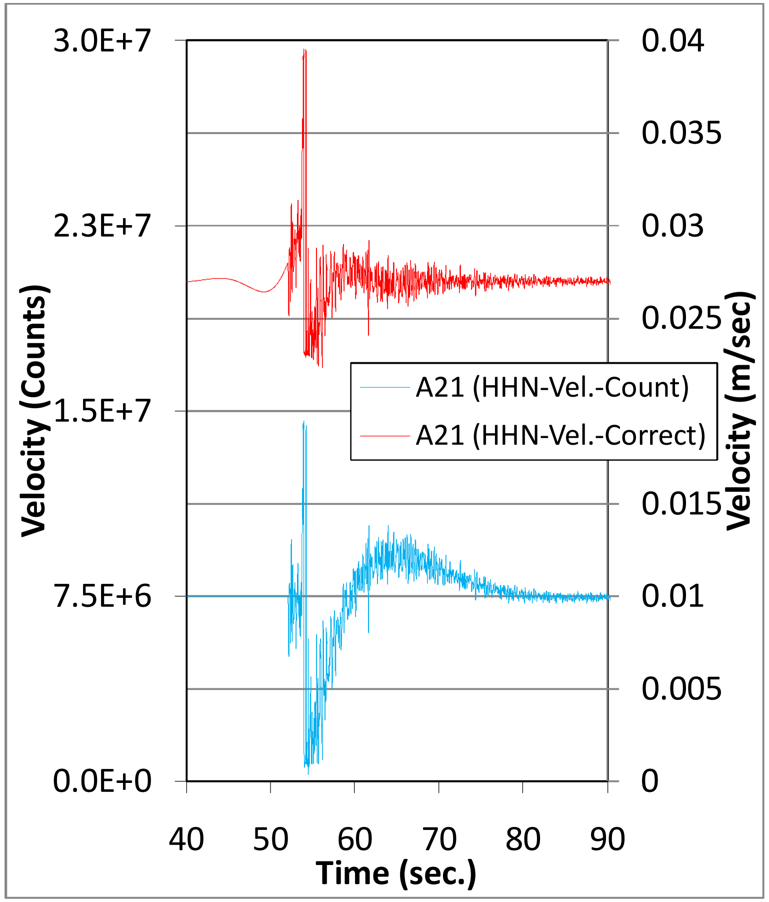


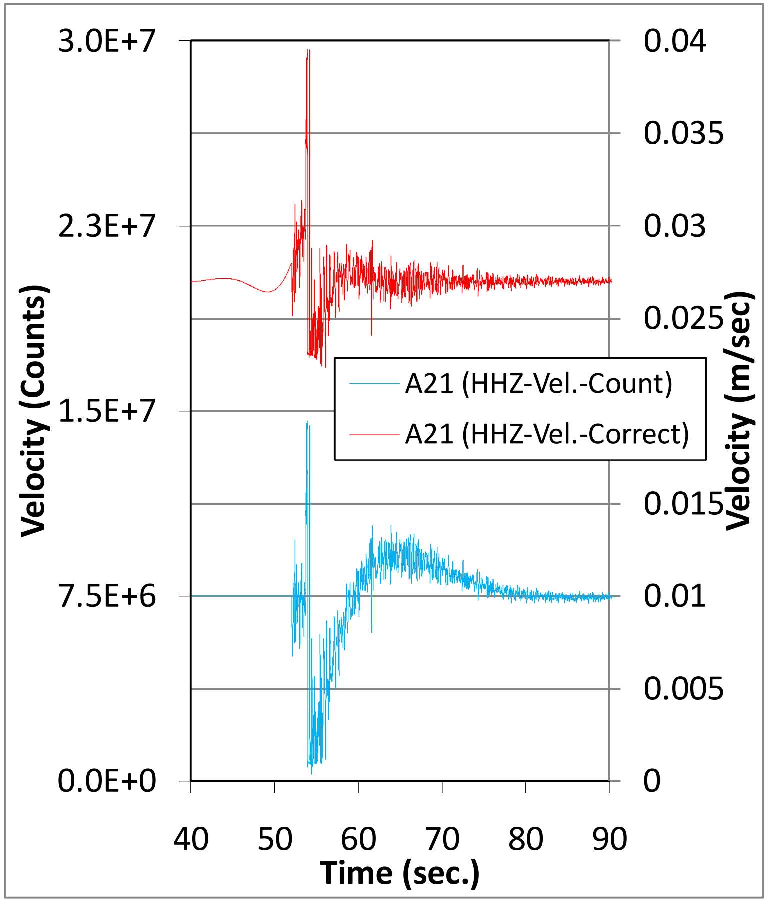
1000
100
10
1
0.1
0.01
PSA (cm/sec^2)
0.1
1
10
Frequency (Hz)
A21 (HNN-GSC)
A21 (HHN-Toolbox)


560
480
400
320
240
160
80
0
Acceleration (cm/sec^2)
40
50
60
70
80
90
Time (sec.)
A21 (HNZ-GSC)
A21 (HHZ-Toolbox)

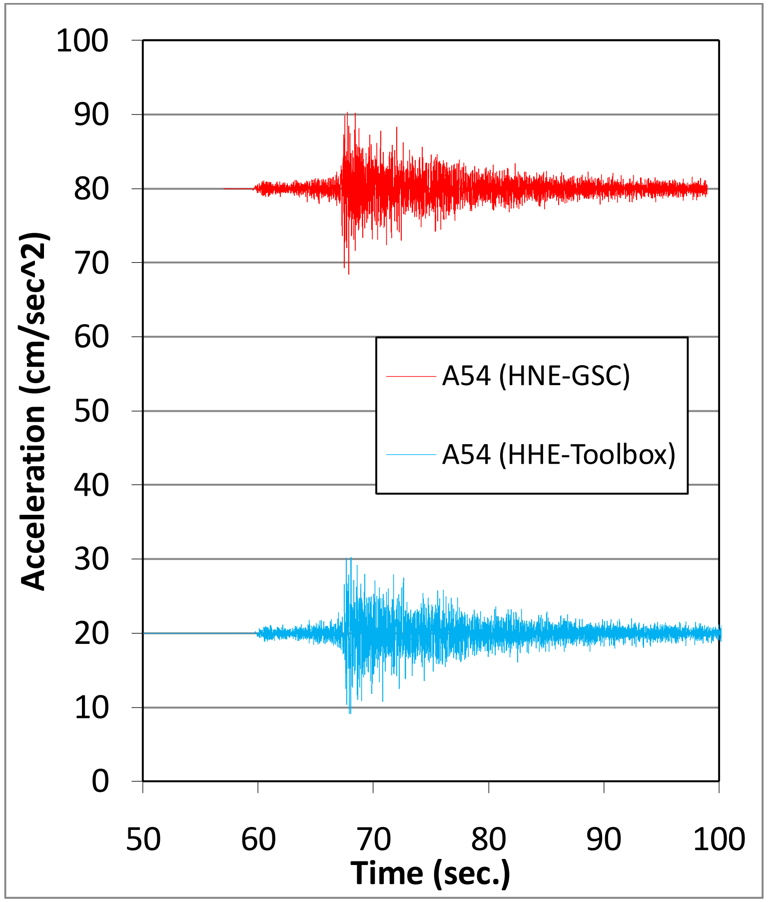

1000
100
10
1
0.1
0.01
PSA (cm/sec^2)
0.1
1
10
Frequency (Hz)
A21 (HNZ-GSC)
A21 (HHZ-Toolbox)

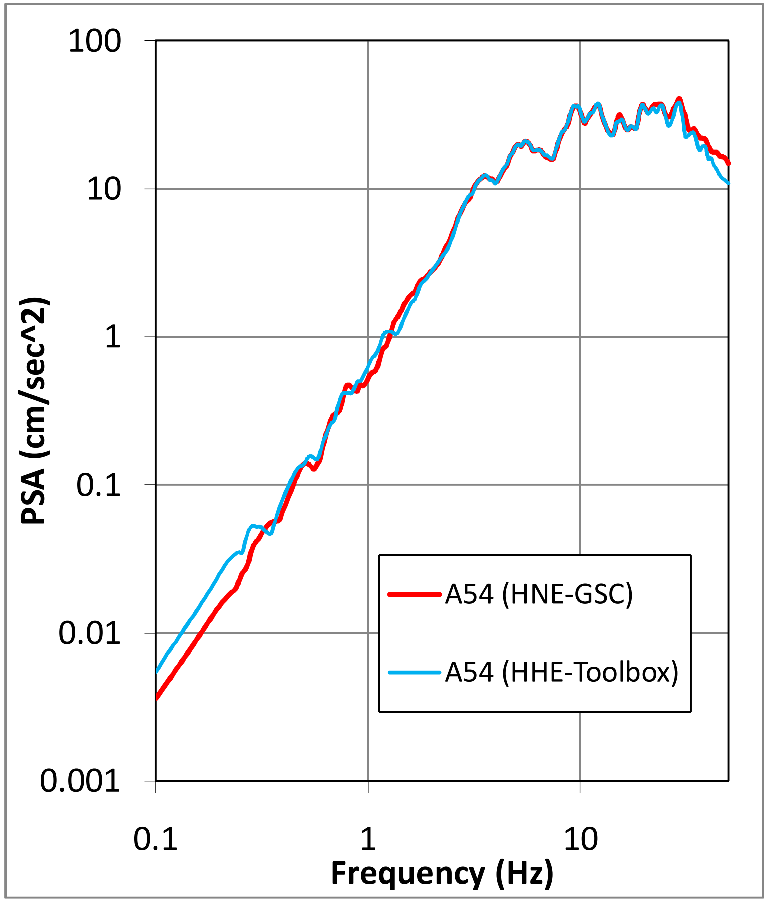

3.0E+7
2.3E+7
1.5E+7
7.5E+6
0.0E+0
0.04
0.035
0.03
0.025
0.015
0.01
0.005
0
Velocity (Counts)
Velocity (m/sec)
A21 (HHE-Vel.-Count)
A21 (HHE-Vel.-Correct)
40
50
60
70
80
90
Time (sec.)

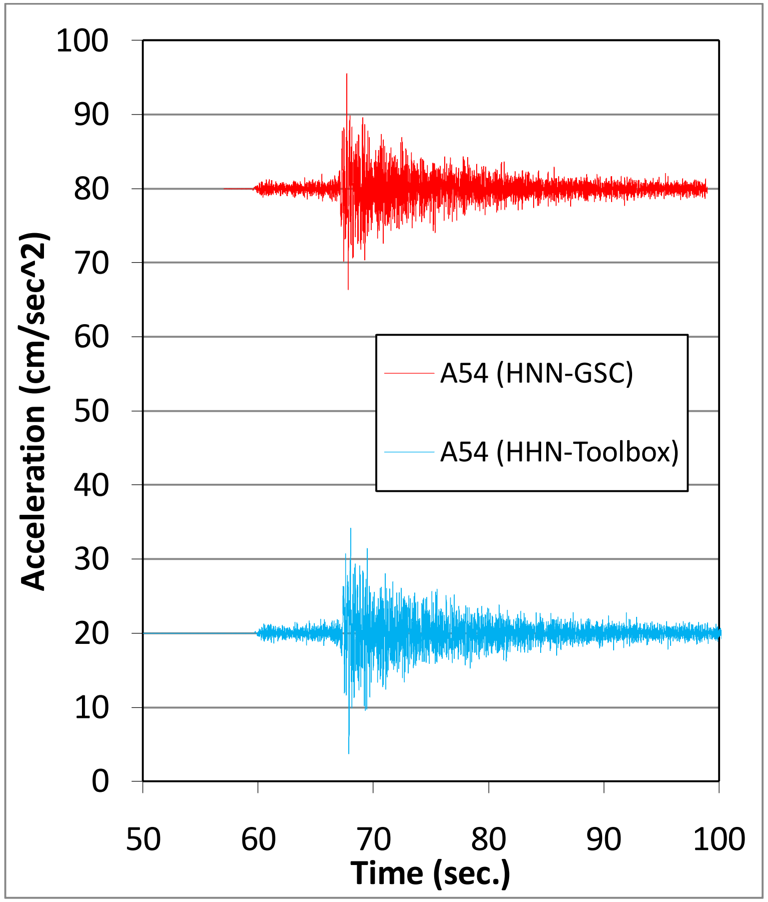

3.0E+7
2.3E+7
1.5E+7
7.5E+6
0.0E+0
0.04
0.035
0.03
0.025
0.015
0.01
0.005
0
Velocity (Counts)
Velocity (m/sec)
A21 (HHN-Vel.-Count)
A21 (HHN-Vel.-Correct)
40
50
60
70
80
90
Time (sec.)



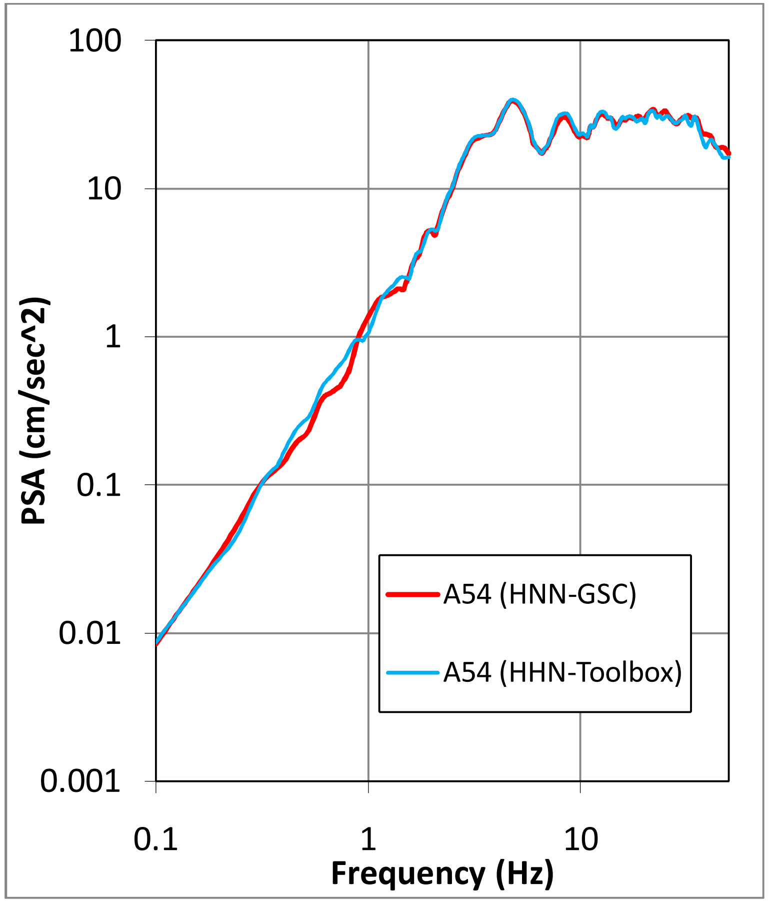
3.0E+7
2.3E+7
1.5E+7
7.5E+6
0.0E+0
Velocity (Counts)
0.04
0.035
0.03
0.025
0.015
0.01
0.005
0
Velocity (m/sec)
40
50
60
70
80
90
Time (sec.)
A21 (HHZ-Vel.-Count)
A21 (HHZ-Vel.-Correct)


100
90
80
70
60
50
40
30
20
10
0
50
60
70
80
90
100
Time (sec.)
Acceleration (cm/sec^2)
A54 (HNE-GSC)
A54 (HHE-Toolbox)

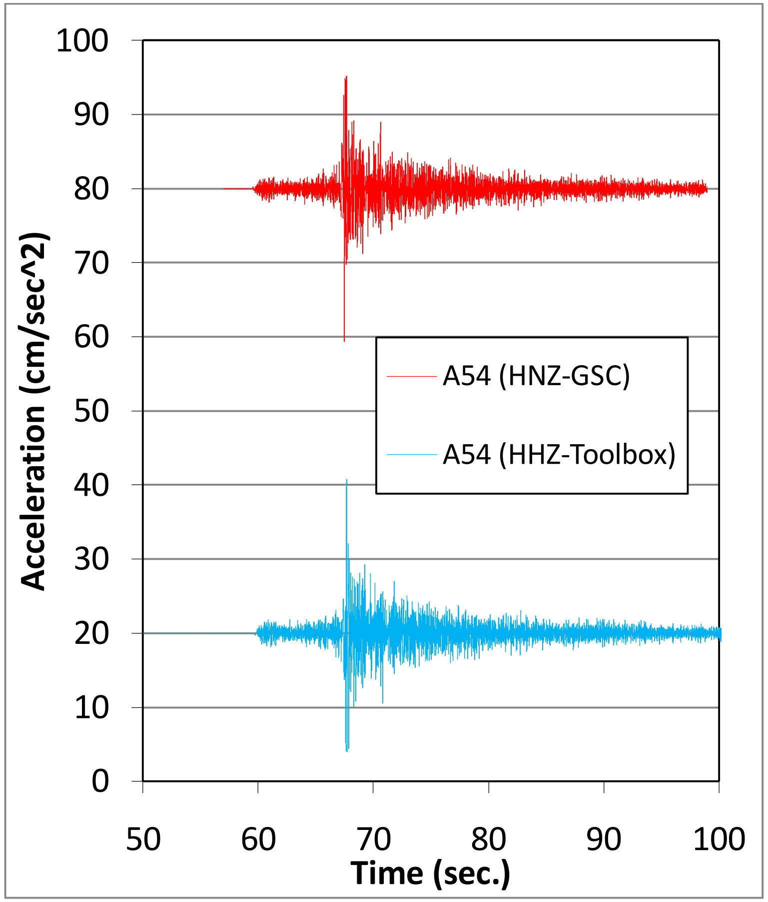

100
10
1
0.1
0.01
0.001
0.1
1
10
Frequency (Hz)
PSA (cm/sec^2)
A54 (HNE-GSC)
A54 (HHE-Toolbox)



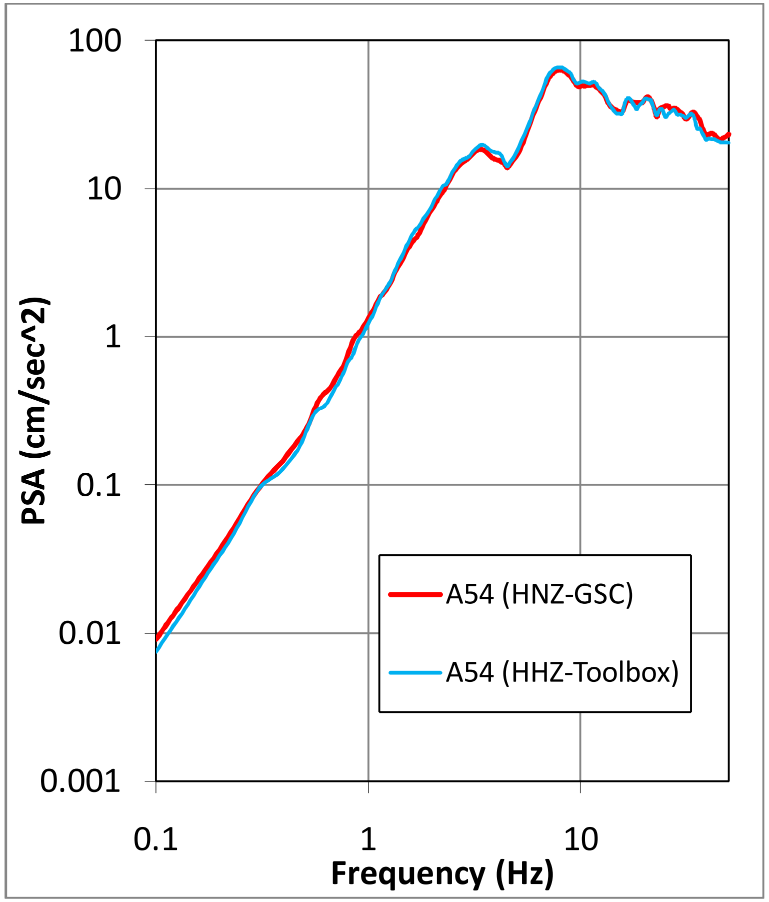
100
90
80
70
60
50
40
30
20
10
0
Acceleration (cm/sec^2)
A54 (HNN-GSC)
A54 (HHN-Toolbox)
50
60
70
80
90
100
Time (sec.)



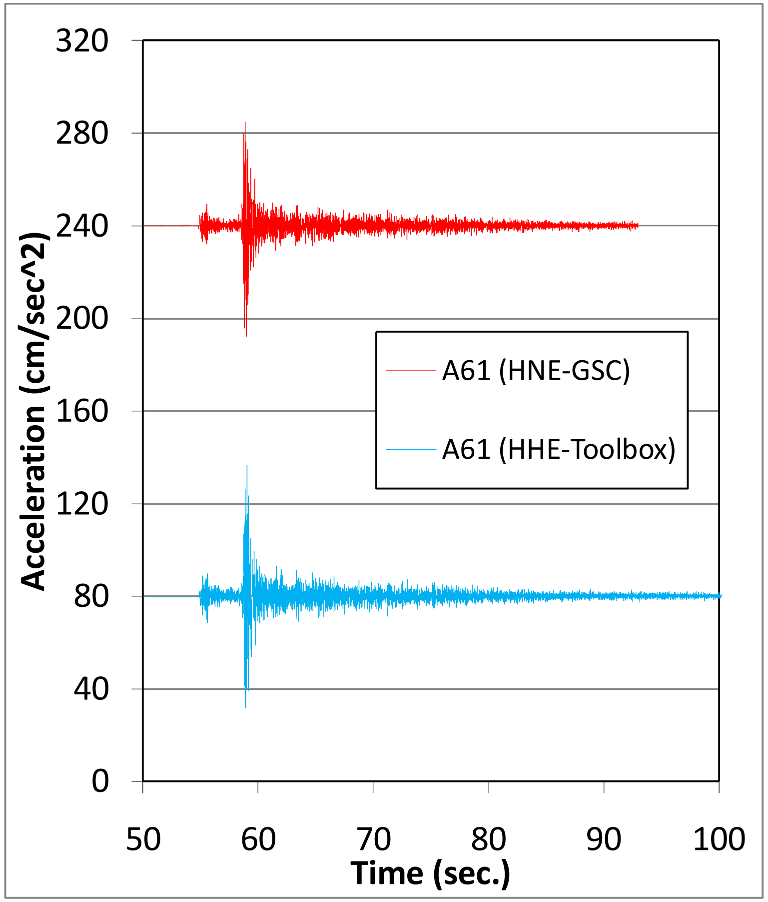
100
10
1
0.1
0.01
0.001
PSA (cm/sec^2)
A54 (HNN-GSC)
A54 (HHN-Toolbox)
0.1
1
10
Frequency (Hz)



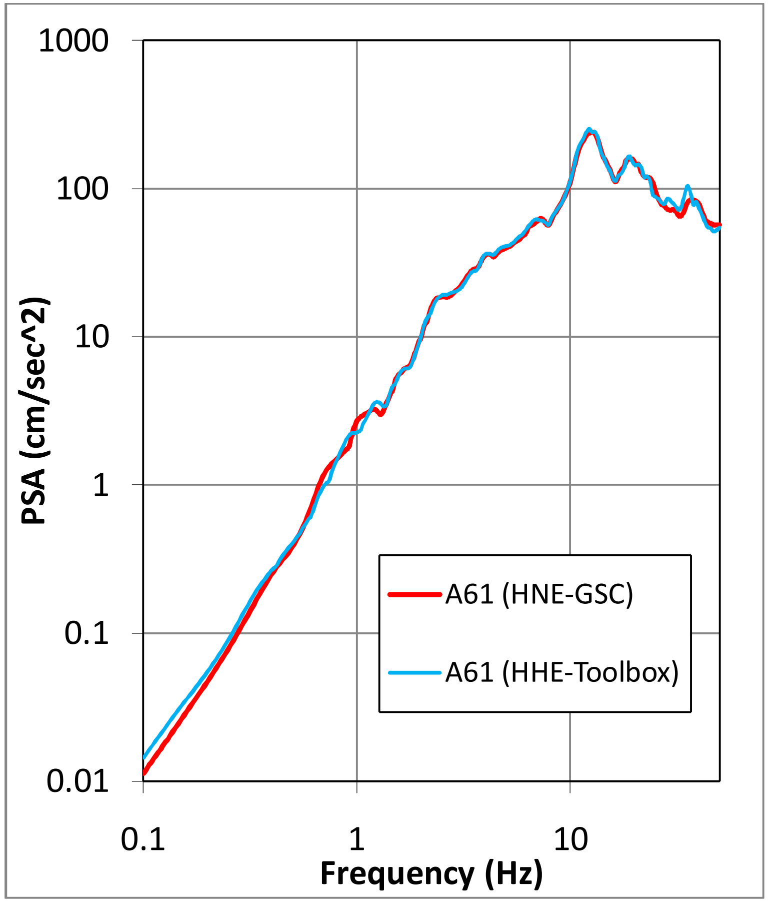
Acceleration (cm/sec^2)
100
90
80
70
60
50
40
30
20
10
0
50
60
70
80
90
100
Time (sec.)
A54 (HNZ-GSC)
A54 (HHZ-Toolbox)



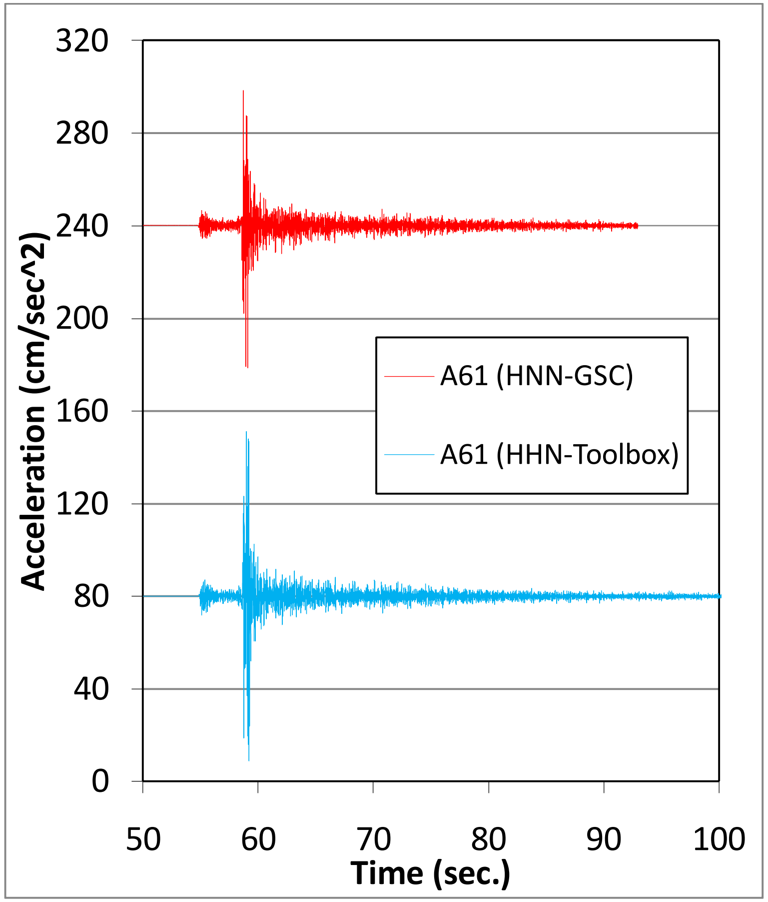
PSA (cm/sec^2)
100
10
1
0.1
0.01
0.001
0.1
1
10
Frequency (Hz)
A54 (HNZ-GSC)
A54 (HHZ-Toolbox)

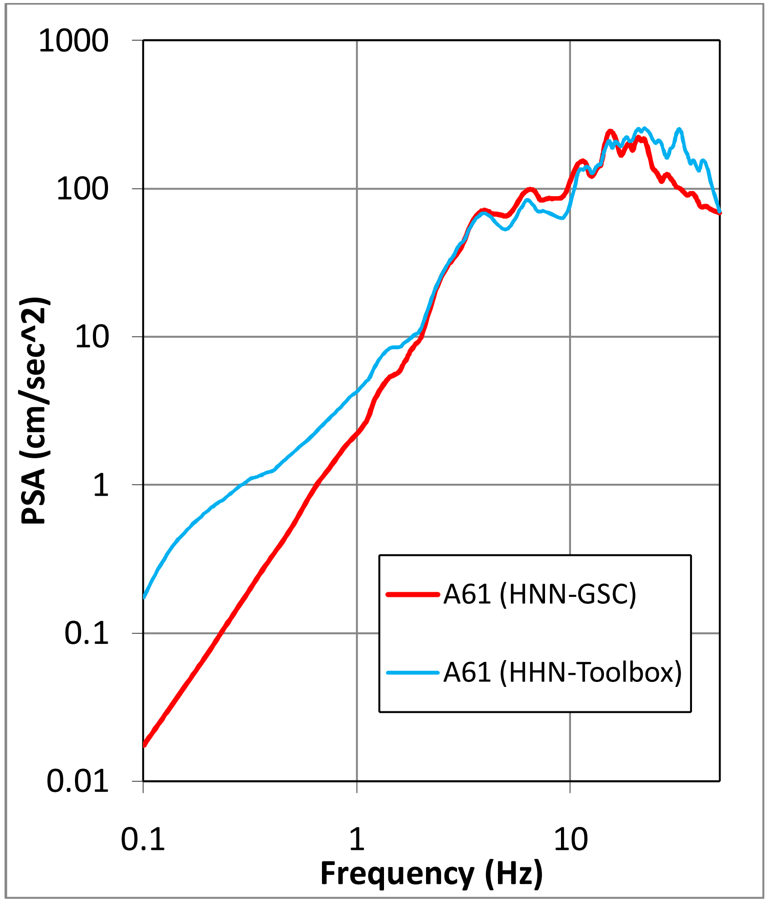


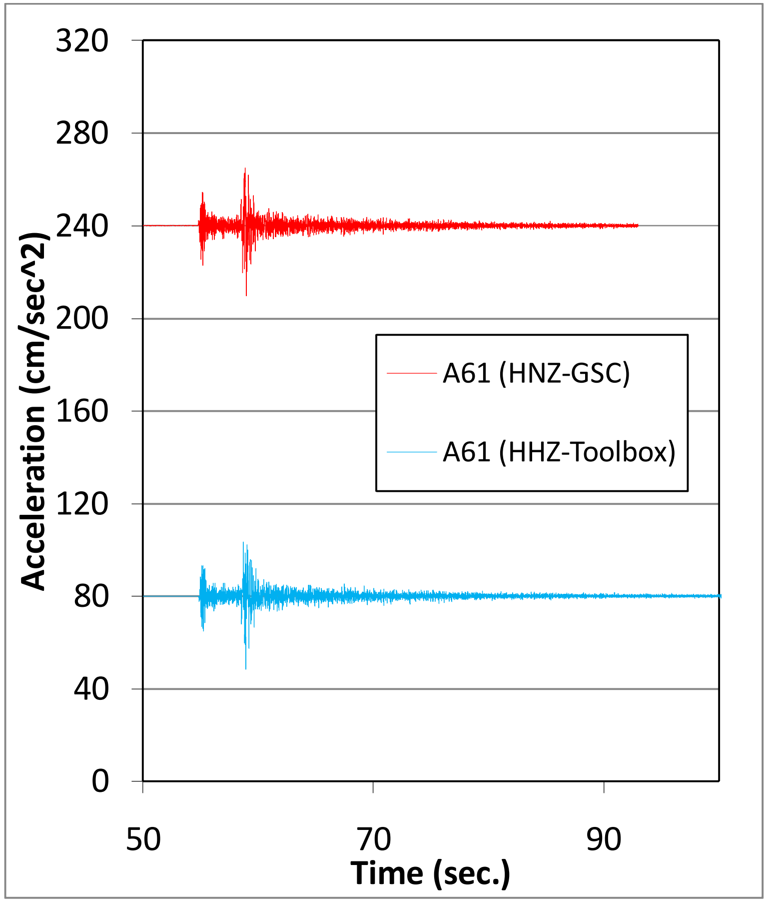
Acceleration (cm/sec^2)
320
280
240
200
160
120
80
40
0
50
60
70
80
90
100
Time (sec.)
A61 (HNE-GSC)
A61 (HHE-Toolbox)



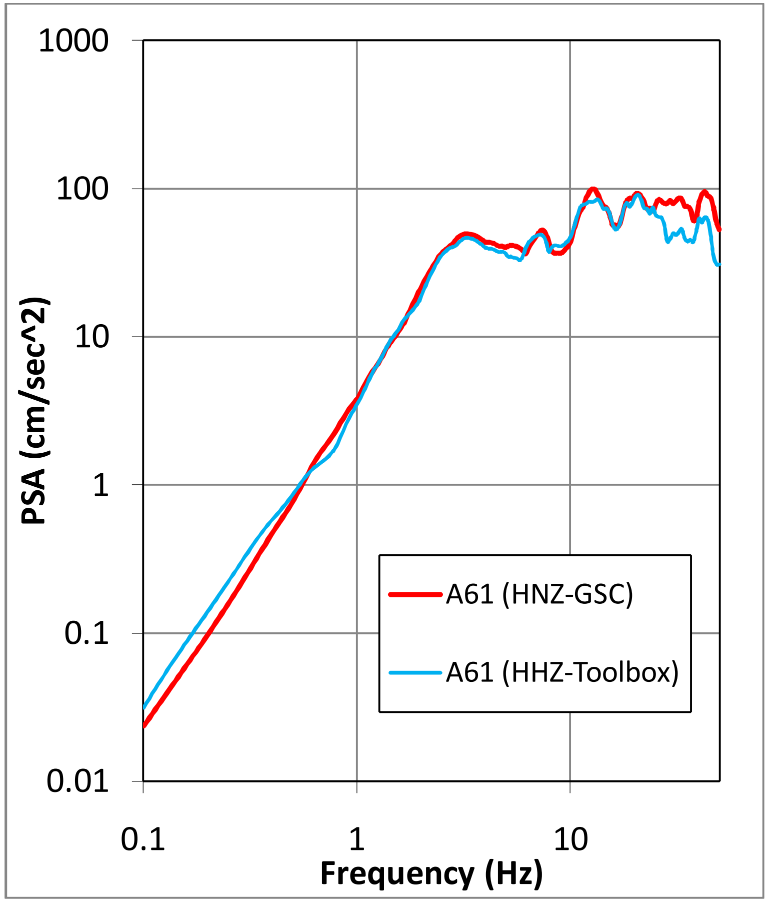
PSA (cm/sec^2)
1000
100
10
1
0.1
0.01
0.1
1
10
Frequency (Hz)
A61 (HNE-GSC)
A61 (HHE-Toolbox)


320
280
240
200
160
120
80
40
0
50
60
70
80
90
100
Acceleration (cm/sec^2)
Time (sec.)
A61 (HNN-GSC)
A61 (HHN-Toolbox)

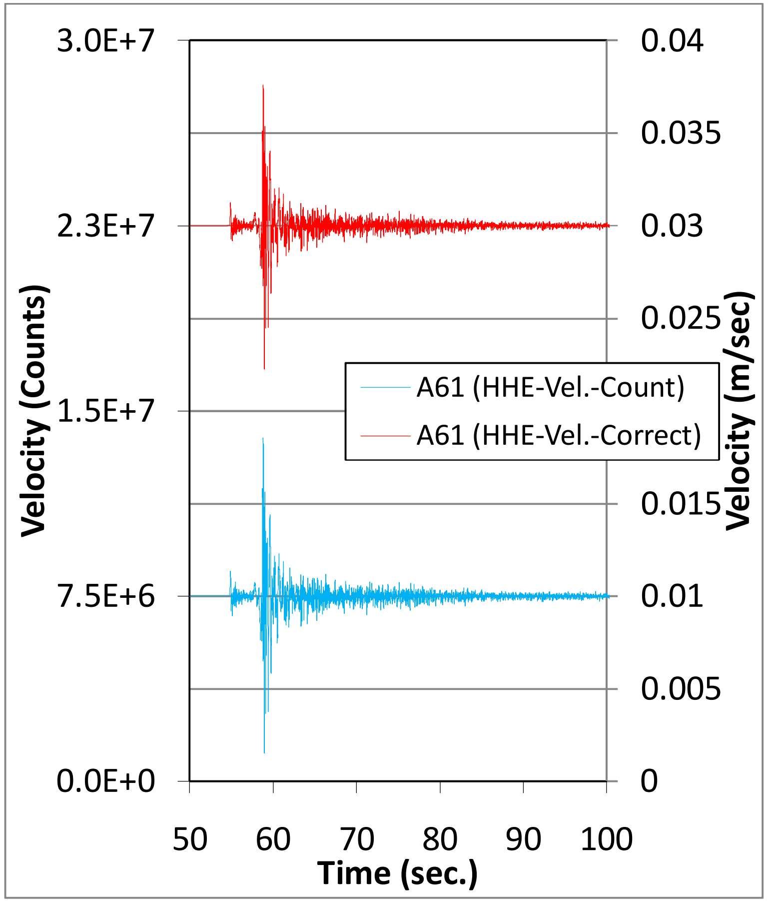

1000
100
10
1
0.1
0.01
0.1
1
10
PSA (cm/sec^2)
Frequency (Hz)
A61 (HNN-GSC)
A61 (HHN-Toolbox)

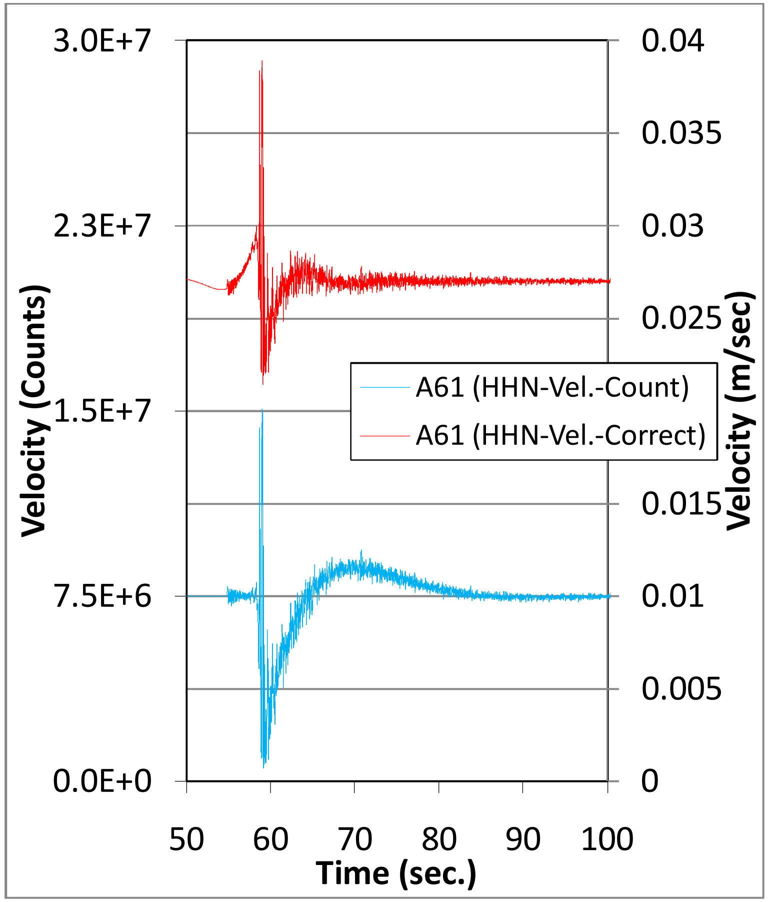


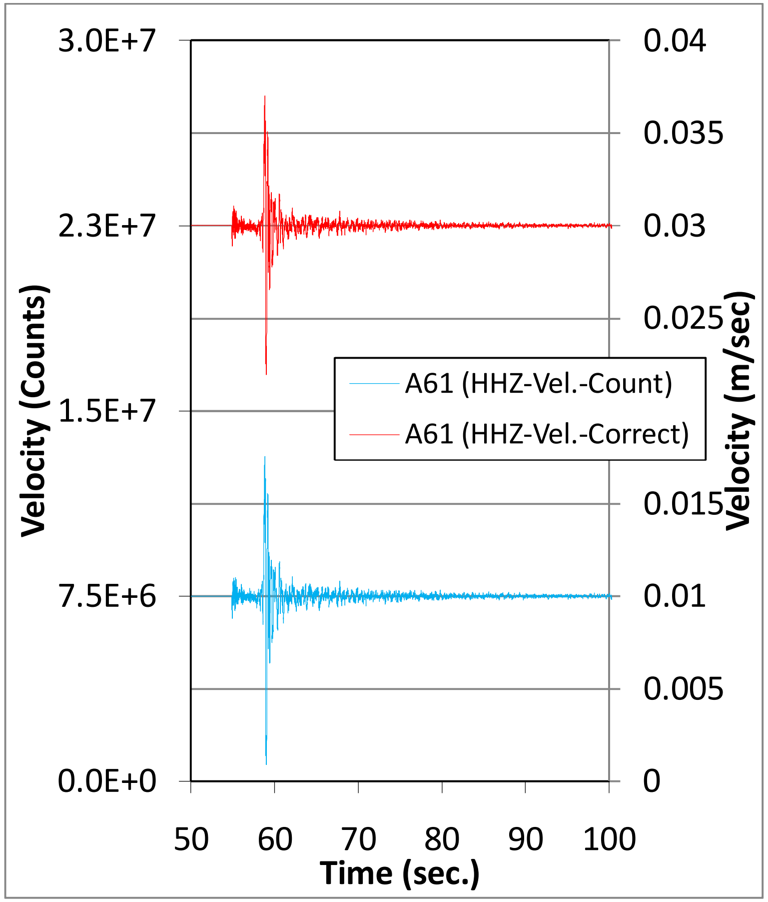
Acceleration (cm/sec^2)
320
280
240
200
160
120
80
40
0
50
70
90
Time (sec.)
A61 (HNZ-GSC)
A61 (HHZ-Toolbox)

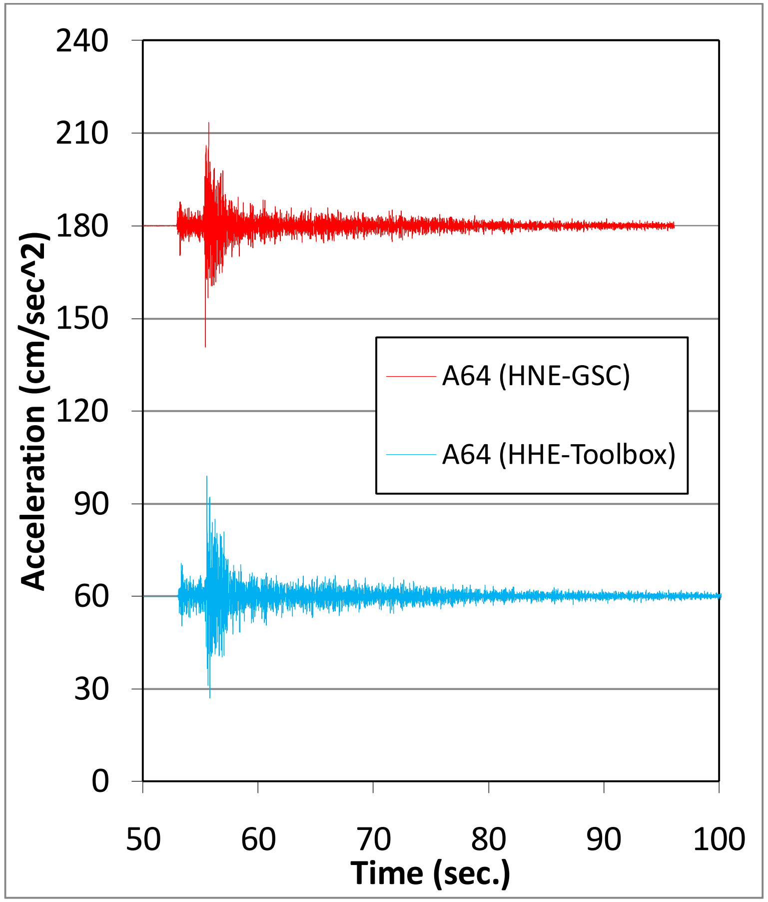


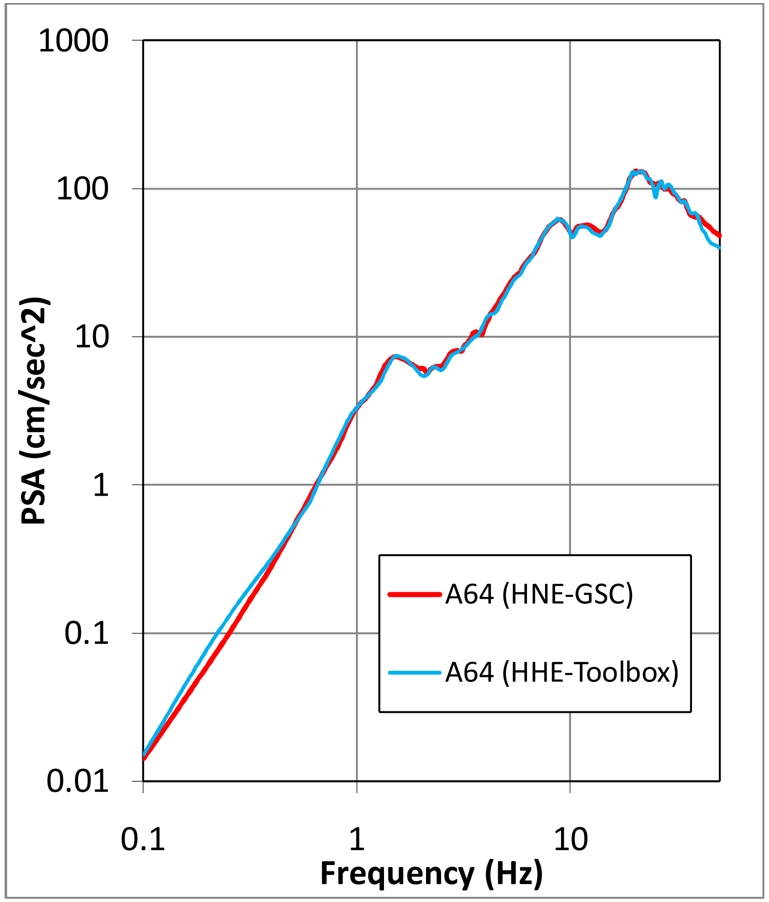
PSA (cm/sec^2)
1000
100
10
1
0.1
0.01
0.1
1
10
Frequency (Hz)
A61 (HNZ-GSC)
A61 (HHZ-Toolbox)

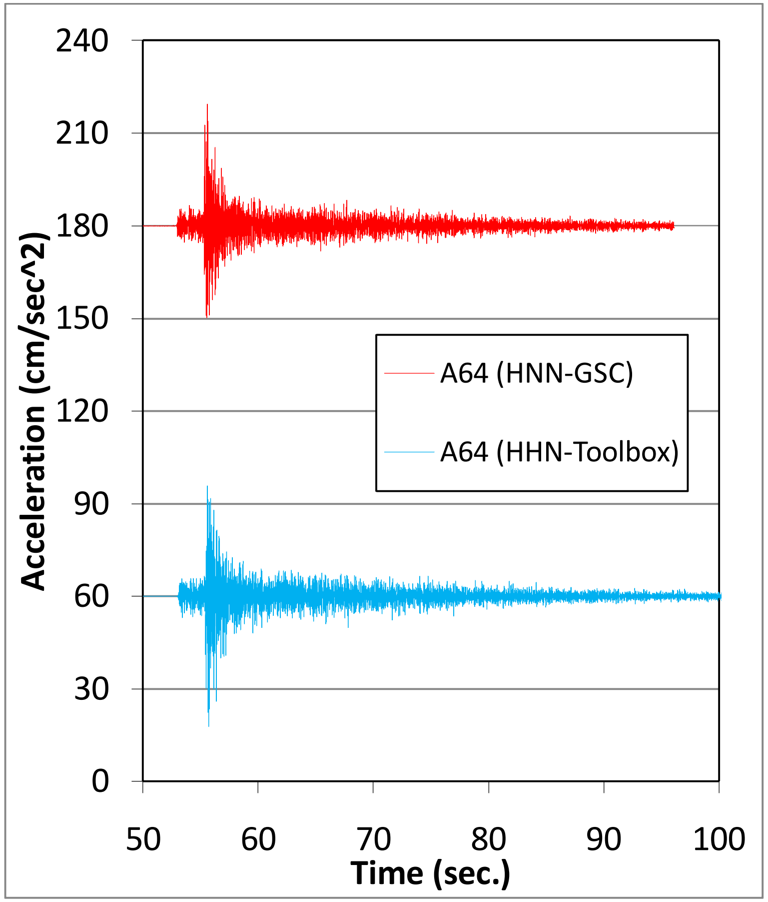

3.0E+7
2.3E+7
1.5E+7
7.5E+6
0.0E+0
0.04
0.035
0.03
0.025
0.015
0.01
0.005
0
Velocity (Counts)
Velocity (m/sec)
A61 (HHE-Vel.-Count)
A61 (HHE-Vel.-Correct)
50
60
70
80
90
100
Time (sec.)

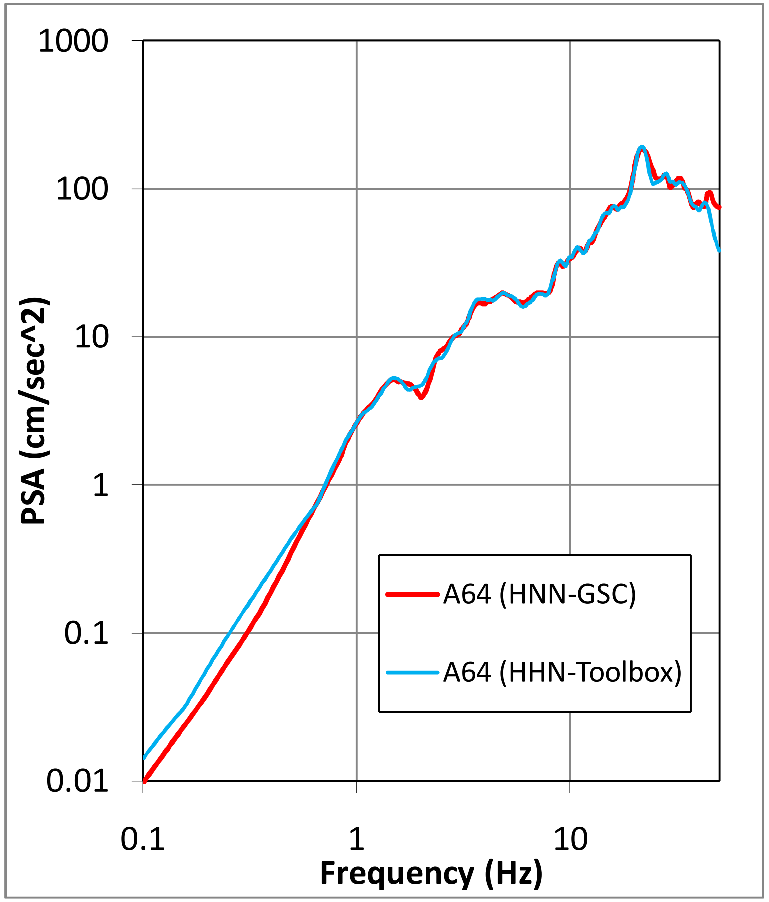

3.0E+7
2.3E+7
1.5E+7
7.5E+6
0.0E+0
0.04
0.035
0.03
0.025
0.015
0.01
0.005
0
Velocity (Counts)
Velocity (m/sec)
A61 (HHN-Vel.-Count)
A61 (HHN-Vel.-Correct)
50
60
70
80
90
100
Time (sec.)

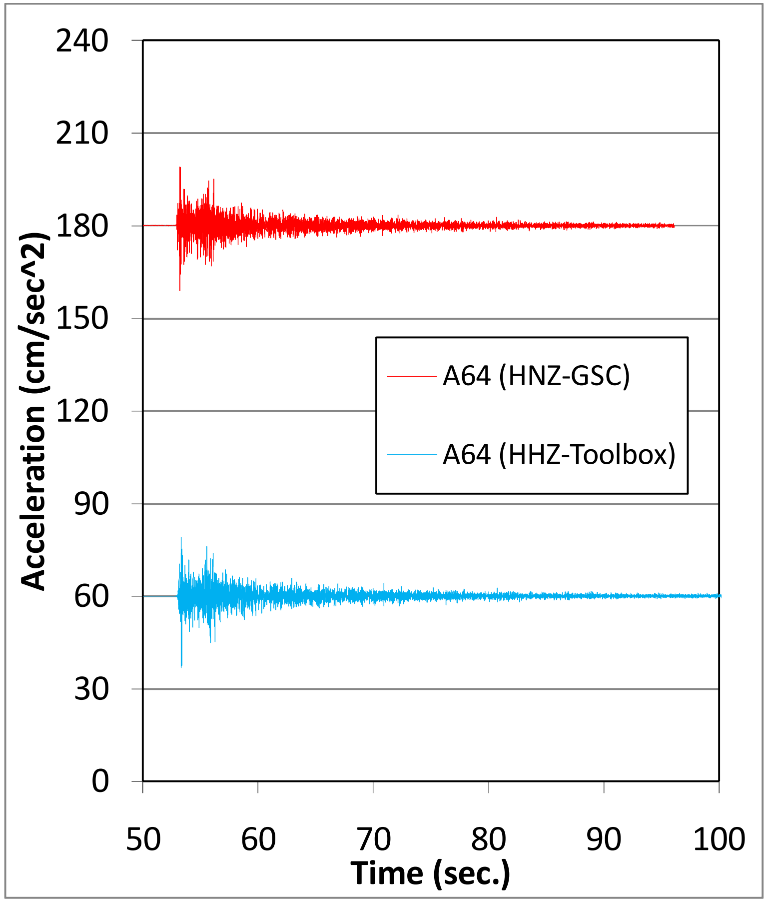

3.0E+7
2.3E+7
1.5E+7
7.5E+6
0.0E+0
Velocity (Counts)
0.04
0.035
0.03
0.025
0.015
0.01
0.005
0
Velocity (m/sec)
A61 (HHZ-Vel.-Count)
A61 (HHZ-Vel.-Correct)
50
60
70
80
90
100
Time (sec.)

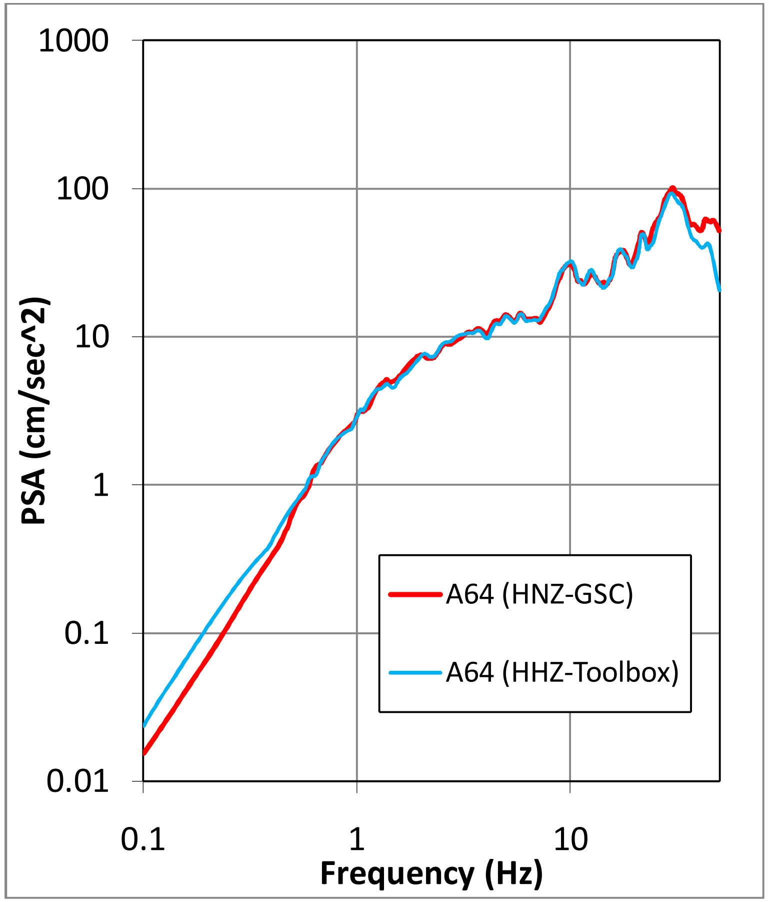

240
210
180
150
120
90
60
30
0
Acceleration (cm/sec^2)
50
60
70
80
90
100
Time (sec.)
A64 (HNE-GSC)
A64 (HHE-Toolbox)


1000
100
10
1
0.1
0.01
PSA (cm/sec^2)
0.1
1
10
Frequency (Hz)
A64 (HNE-GSC)
A64 (HHE-Toolbox)

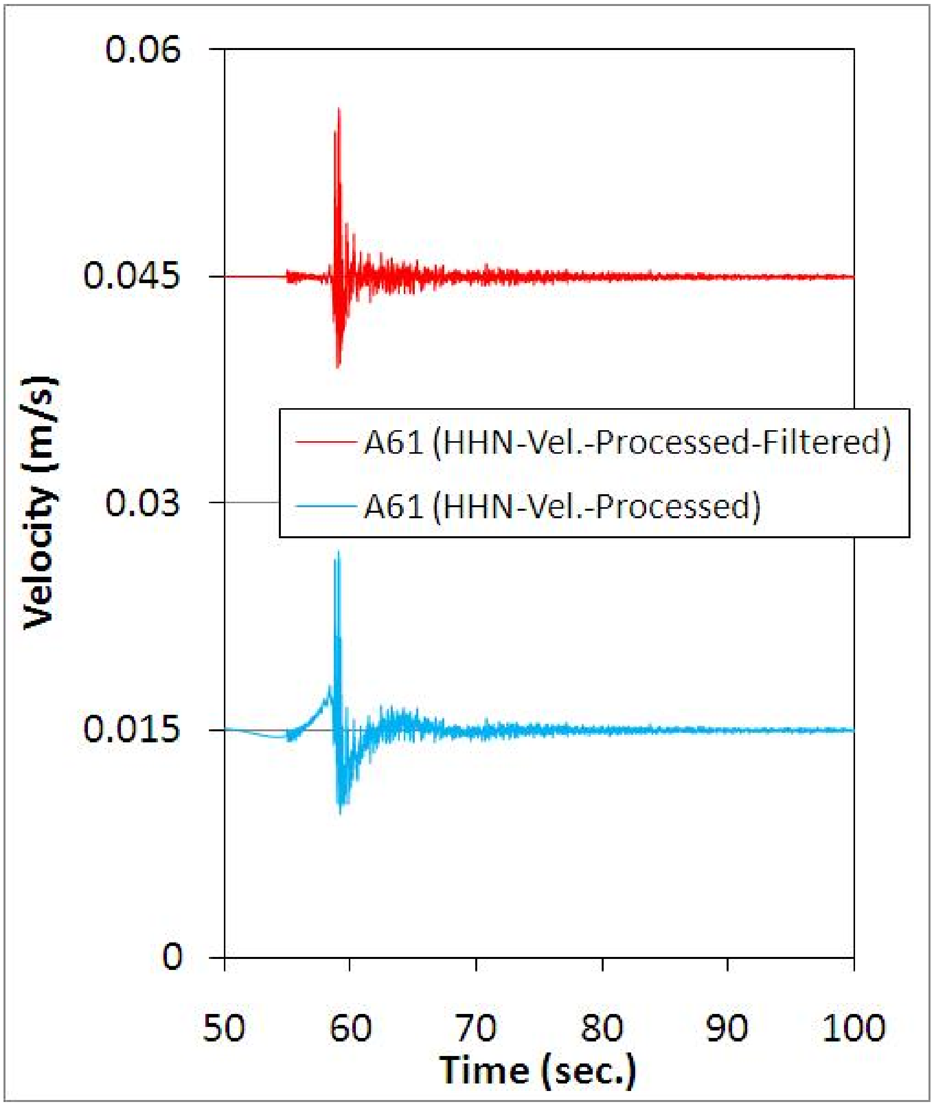

240
210
180
150
120
90
60
30
0
50
60
70
80
90
100
Time (sec.)
Acceleration (cm/sec^2)
A64 (HNN-GSC)
A64 (HHN-Toolbox)

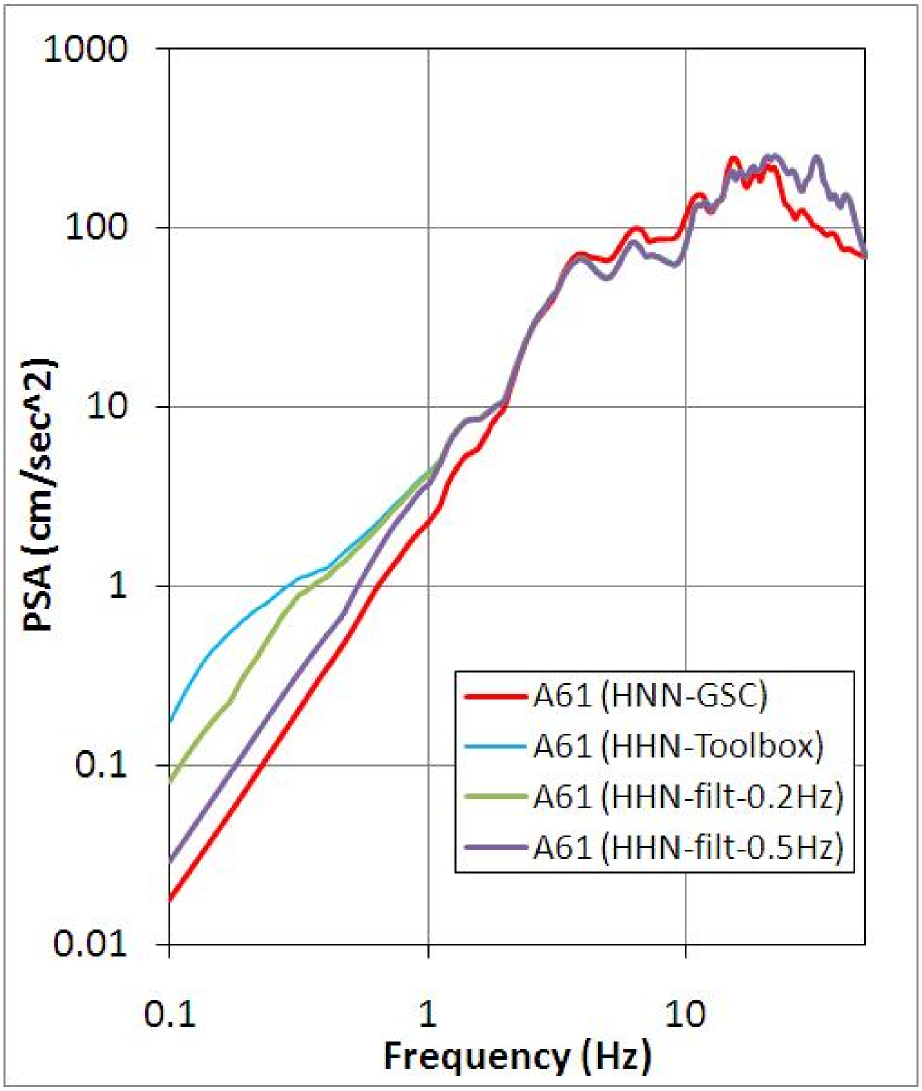

1000
100
10
1
0.1
0.01
0.1
1
10
Frequency (Hz)
PSA (cm/sec^2)
A64 (HNN-GSC)
A64 (HHN-Toolbox)


240
210
180
150
120
90
60
30
0
Acceleration (cm/sec^2)
50
60
70
80
90
100
Time (sec.)
A64 (HNZ-GSC)
A64 (HHZ-Toolbox)


1000
100
10
1
0.1
0.01
PSA (cm/sec^2)
0.1
1
10
Frequency (Hz)
A64 (HNZ-GSC)
A64 (HHZ-Toolbox)

Appendix: Part B – Comparison of Corrected velocity traces of A61N after high-pass filtering at 0.5s. Effect of filtering on the response spectra is also shown.




1000
100
10
1
0.1
0.01
PSA (cm/sec^2)
0.1
1
10
Frequency (Hz)
A61 (HNN-GSC)
A61 (HHN-Toolbox)
A61 (HHN-filt-0.2Hz)
A61 (HHN-filt-0.5Hz)