# Seismic Analysis and Testing of Launch Vehicles and Equipment using Historical Strong Motion Data Scaled to Satisfy Shock Response Spectra Specifications

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# Topics



1. Seismic analysis and testing of launch vehicles and equipment using historical strong motion data scaled to satisfy shock response spectra specifications

2. Temporal Moments

# Introduction

- Consider the following type of equipment:

  Telecommunication
  Medical life-support
  Network servers
  Nuclear power plant control consoles

- Now consider that this equipment is to be installed in buildings in an active seismic zone

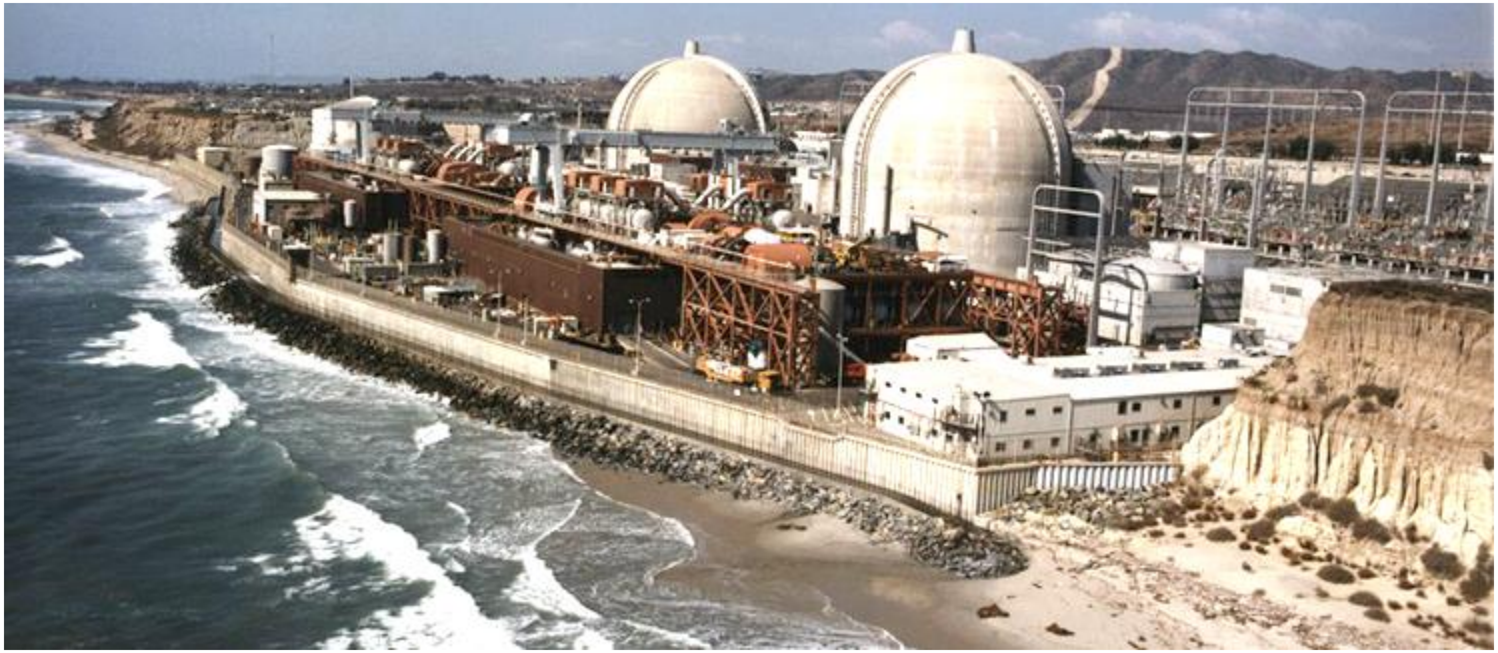
- The equipment must be designed and tested accordingly to withstand the dynamic loads

- A typical specification format for the loading is the shock response spectrum (SRS)

- The testing is performed on a shaker table

# San Onofre Nuclear Power Plant





Nuclear plant equipment must be tested to seismic shock specifications.

# Generator Subjected to Seismic Test



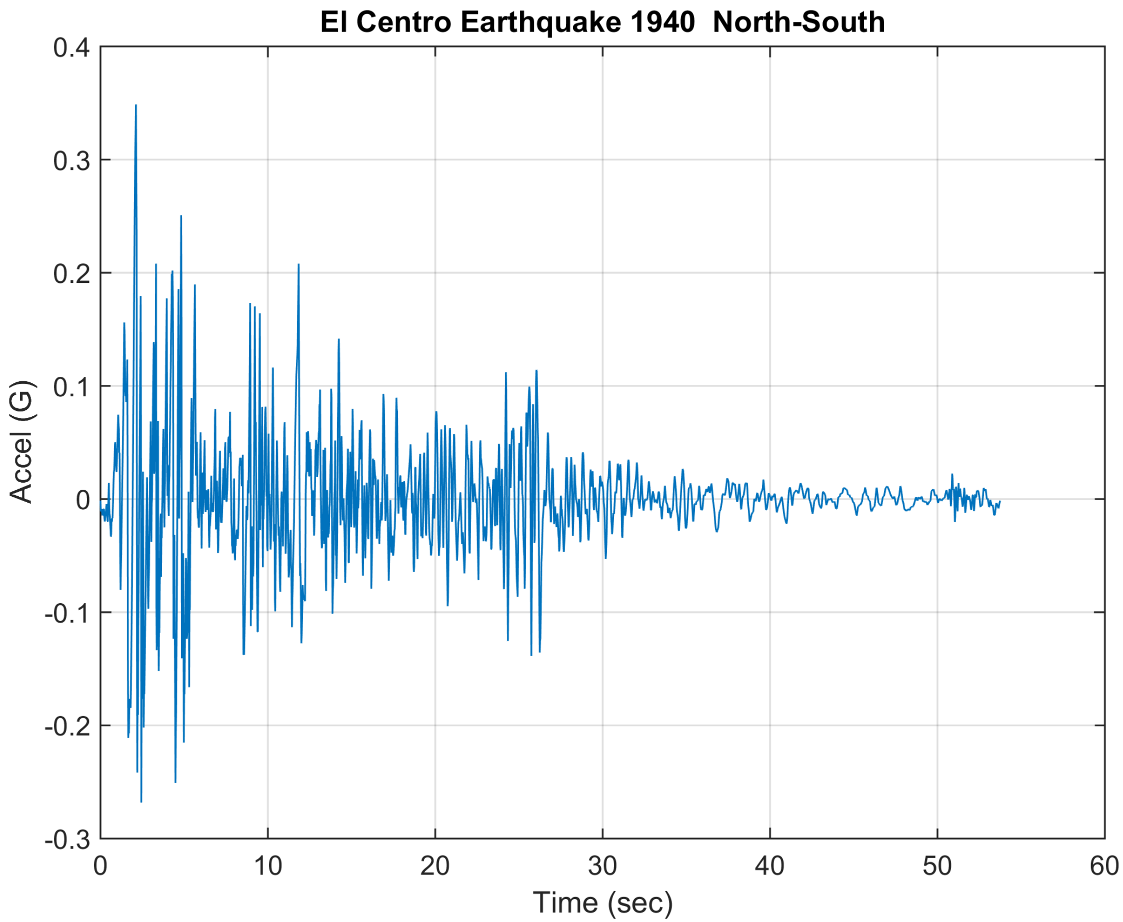
# Falcon 9, Launched from Vandenberg



The vehicle as mounted on the pad is a tall cantilever beam.   Its ability to withstand seismic events must be verified via analysis.

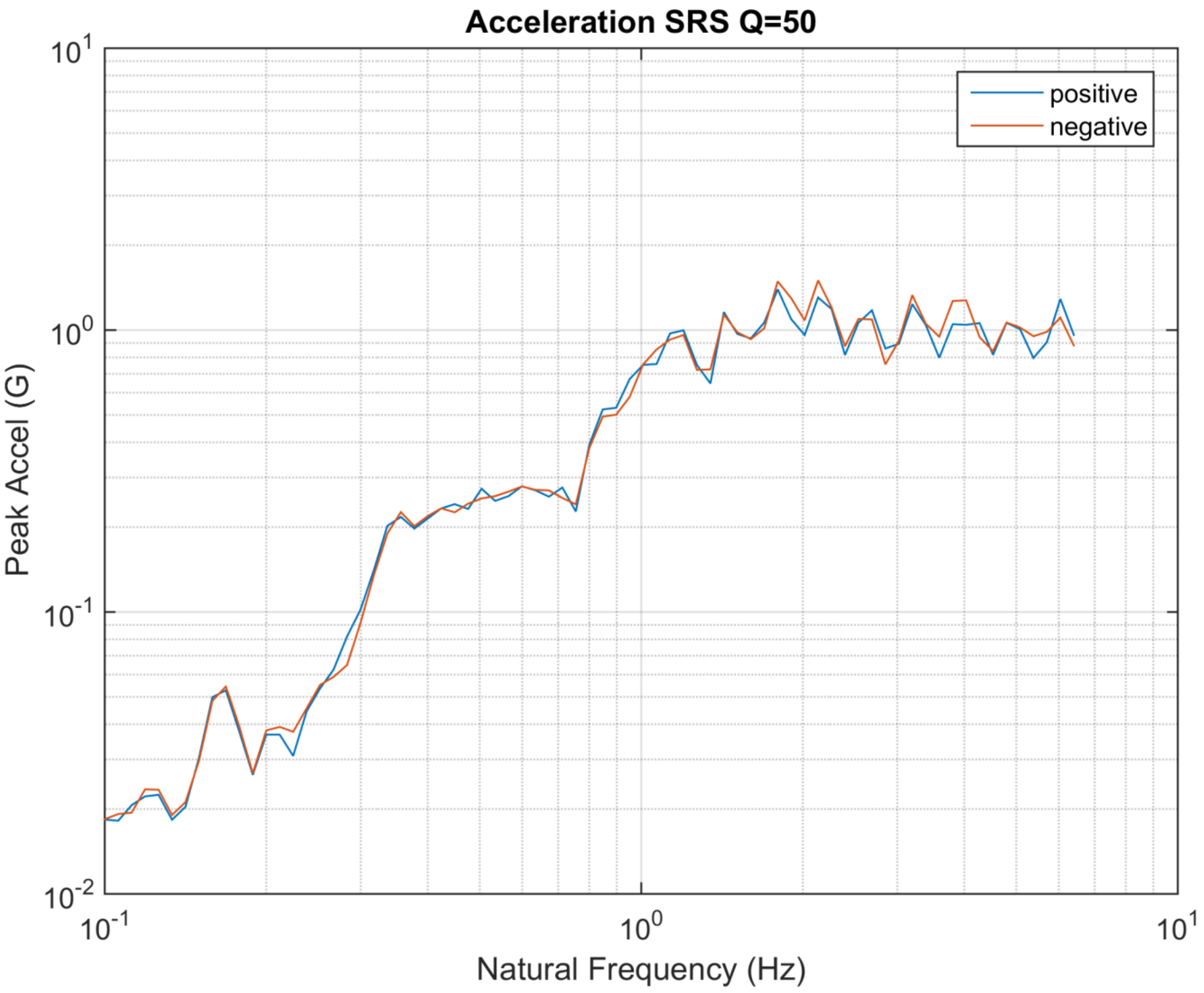
# El Centro Strong Motion Data

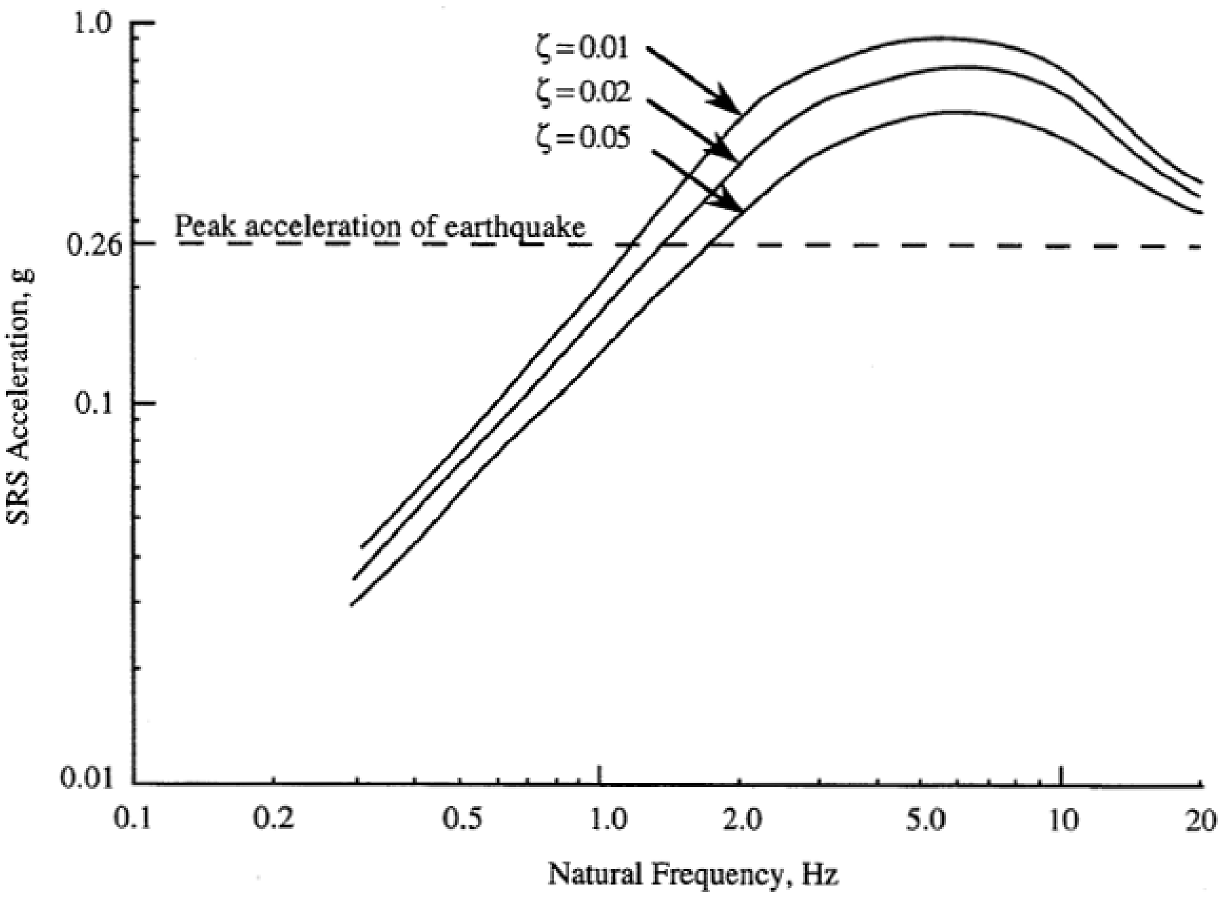




## El Centro NS SRS







1.0
0.26
0.1
0.01
SRS Acceleration, g
ζ=0.01
ζ=0.02
ζ=0.05
Peak acceleration of earthquake
0.1
0.2
0.5
1.0
2.0
5.0
10
20
Natural Frequency, Hz

# SRS Synthesis



- A given time history has a unique SRS
- On the other hand, a given SRS may be satisfied by a variety of base inputs within prescribed tolerance bands
- The SRS format thus offers flexibility
- A common testing approach is to use a burst of wavelets such that the synthesized time history resembles a transient sine sweep with descending frequency

# Synthesis Concerns



- The drawback is that the time history used to satisfy the SRS may be very dissimilar from the measured source data.
- This brings us a number of concerns including linearity and multi-modal response
- Some of these concerns can be quantified in terms of the scalar temporal moments which quantify the energy, RMS, skewness and kurtosis.
- These concerns have led to a desire to synthesize a time history which “resembles” the real-world event while still satisfying the SRS
- The purpose of this paper is present a method which uses a measured reference time history as a basis for synthesizing a time history to meet the SRS specification

# Method Description, Step 1



- The following steps use trial-and-error-random number generation with some built-in convergence
- The method is implemented as a function in the Vibrationdata Matlab GUI package
- The first step is to decompose the reference time history into a series of wavelets
- An acceleration wavelet has zero net velocity and zero net displacement
- A series of wavelets likewise has these properties
- Wavelets are very amenable to shaker table shock testing and are also convenient for analysis
- The examples in the paper use a series of 200 wavelets to model a reference time history

# Method Description, Step 2

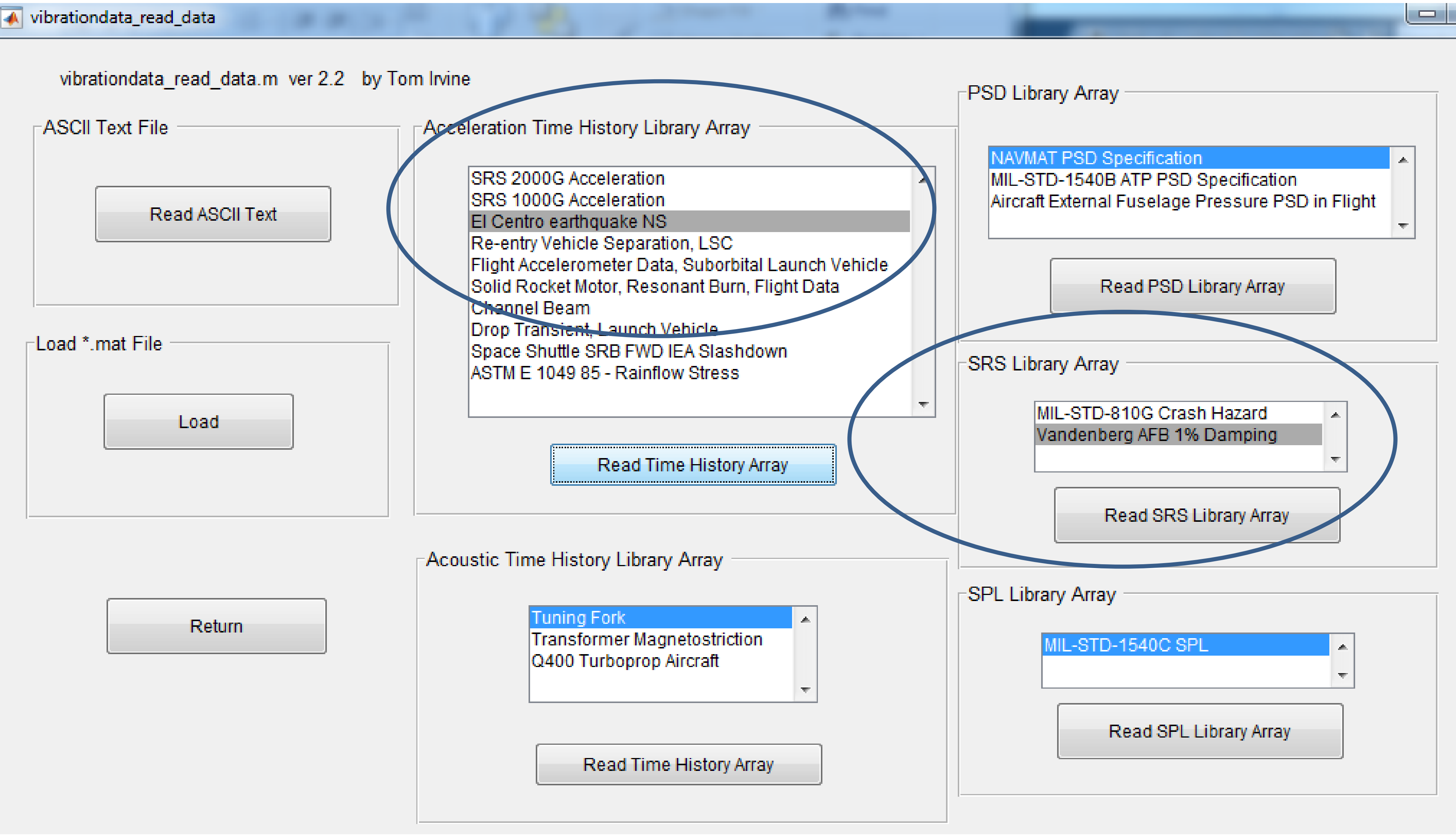


- The second step is to randomly vary the wavelet amplitudes so that the modified wavelet series will have an SRS that matches the specification as closely as possible
- The number of iterations may be 16000 or so
- The modified time history will thus have some distortion relative to the reference, but this is needed to shape the time history so that its SRS meets the specification
- The second step yields an SRS that has some peaks and dips relative to the specification
- This is a consequence of trying to adapt a measured time history to a smoothed SRS

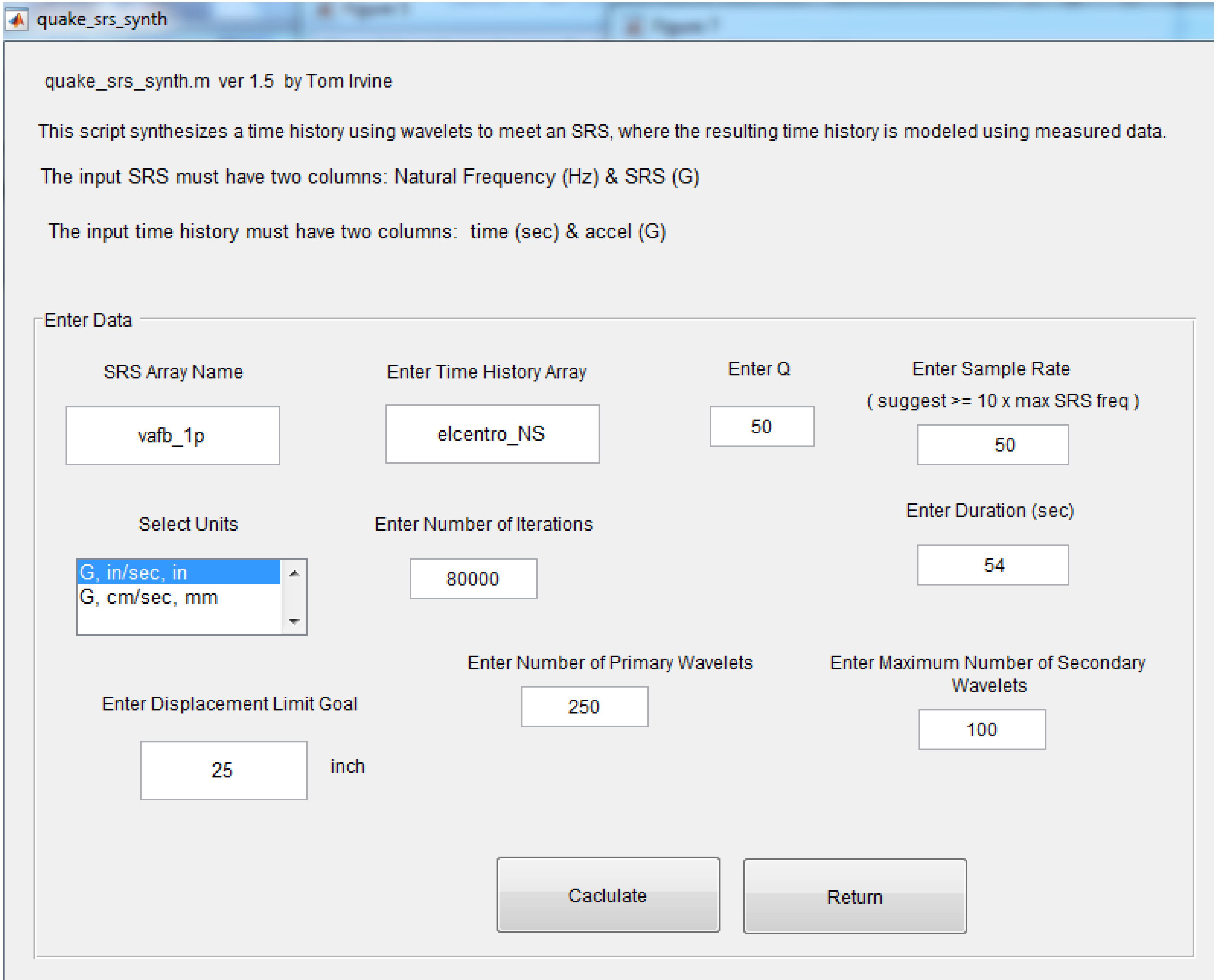
# Method Description, Step 3



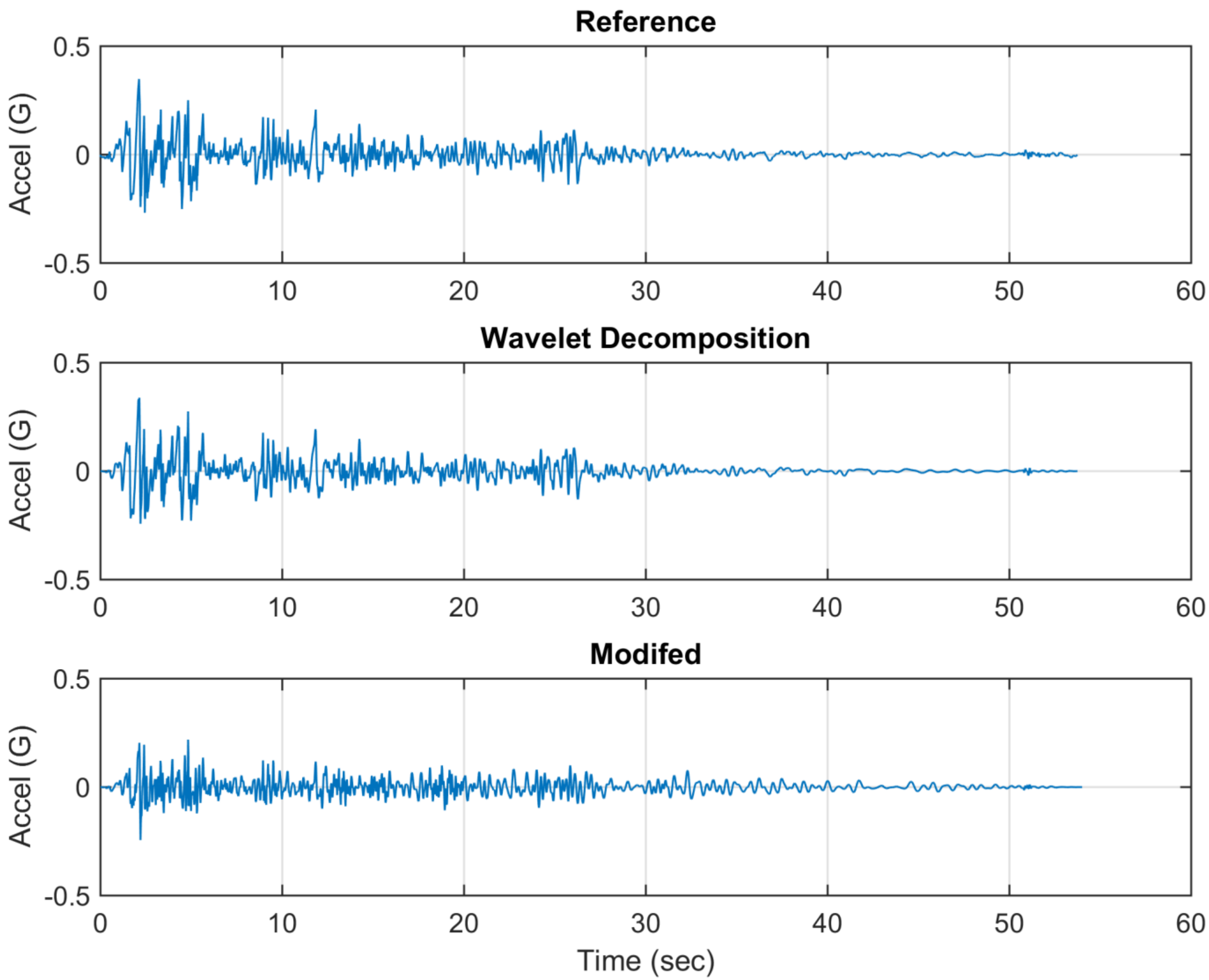
- The third step is to add wavelets so that the resulting SRS meets the specification within, say, $\pm$ 3 dB tolerance limits
- The third step also adds some distortion
- The amount of distortion depends largely on how much the SRS specification differs from that of the reference data



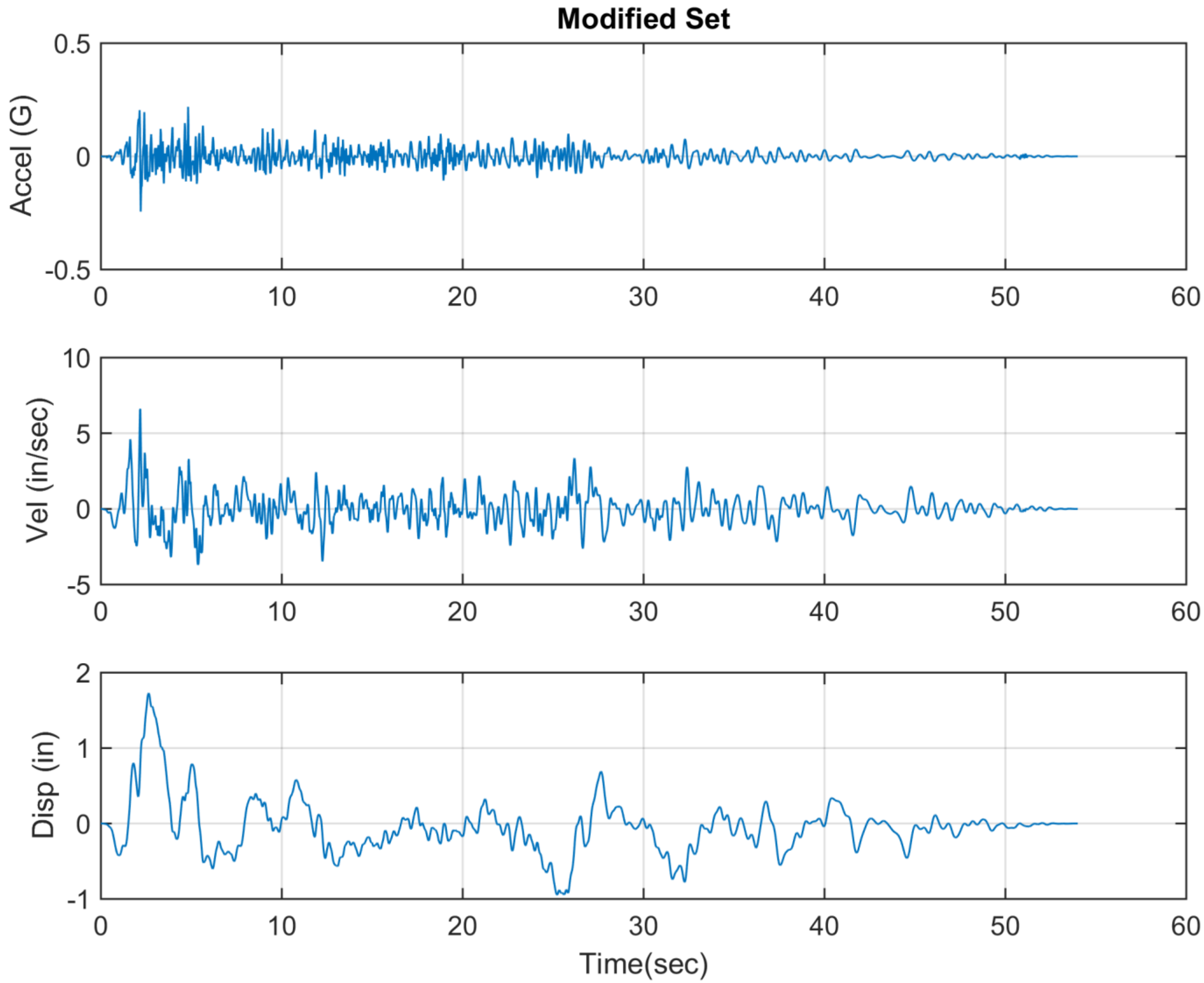

Read in El Centro earthquake NS & Vandenberg SRS Specification



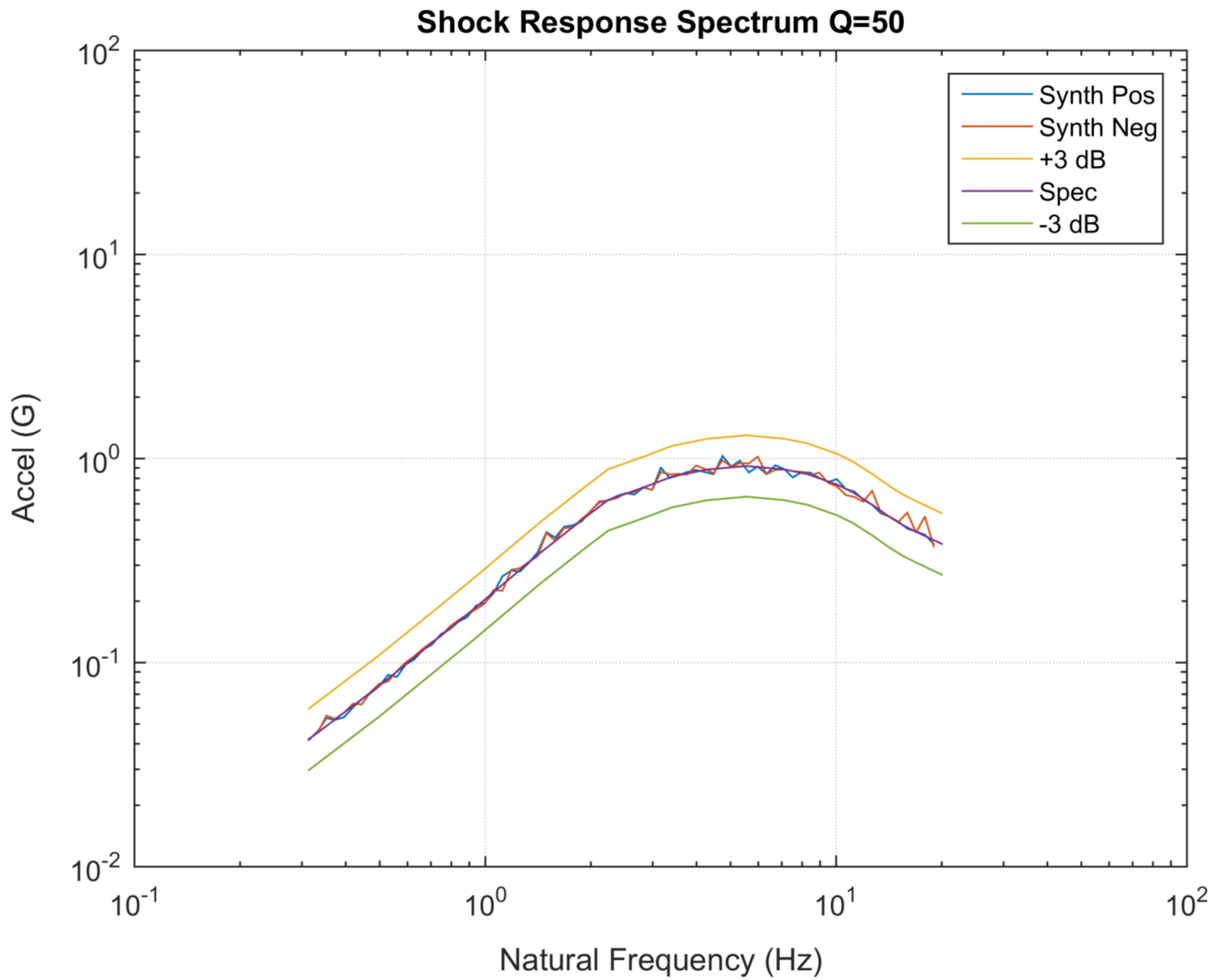

Shock Response Spectrum > Earthquake Synthesis




- The top time history is the measured El Centro NS data
- The middle time history is the wavelet series model.
- The bottom time history has additional wavelets to improve the SRS match, and it is scaled downward since the El Centro SRS plateau is greater than the specification

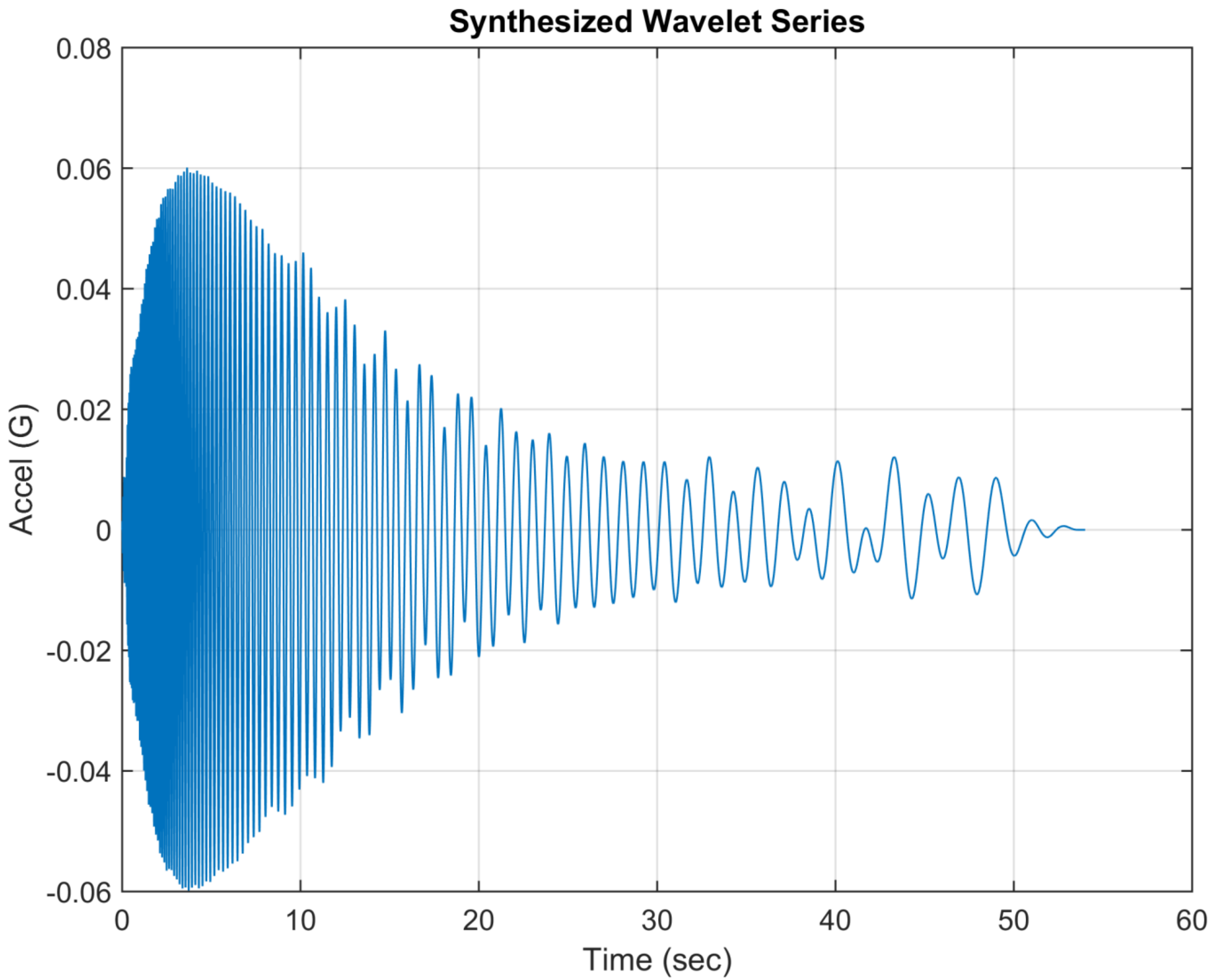


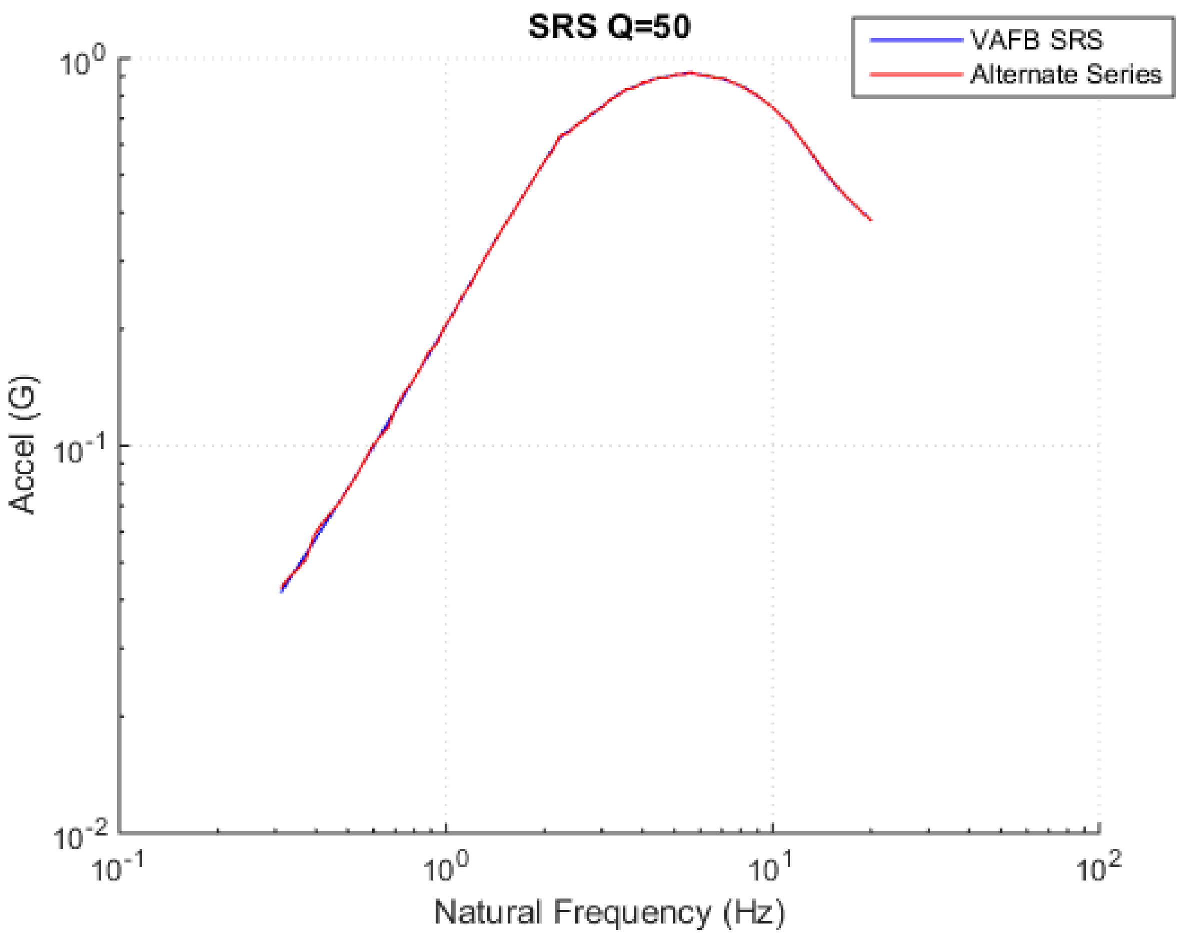

The velocity and displacement time histories are well-behaved which is important for both testing and analysis.




The SRS of the modified, or synthesized, time history is within $\pm$ 3 dB of the nominal specification. The method is thus successful in generating an El Centro-like time history to meet the specification.

## Satisfy Same Specification with Alternate Time History




SRS Q=50
VAFB SRS
Alternate Series
Accel (G)
Natural Frequency (Hz)
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-1}$
$10^{0}$
$10^{1}$
$10^{2}$

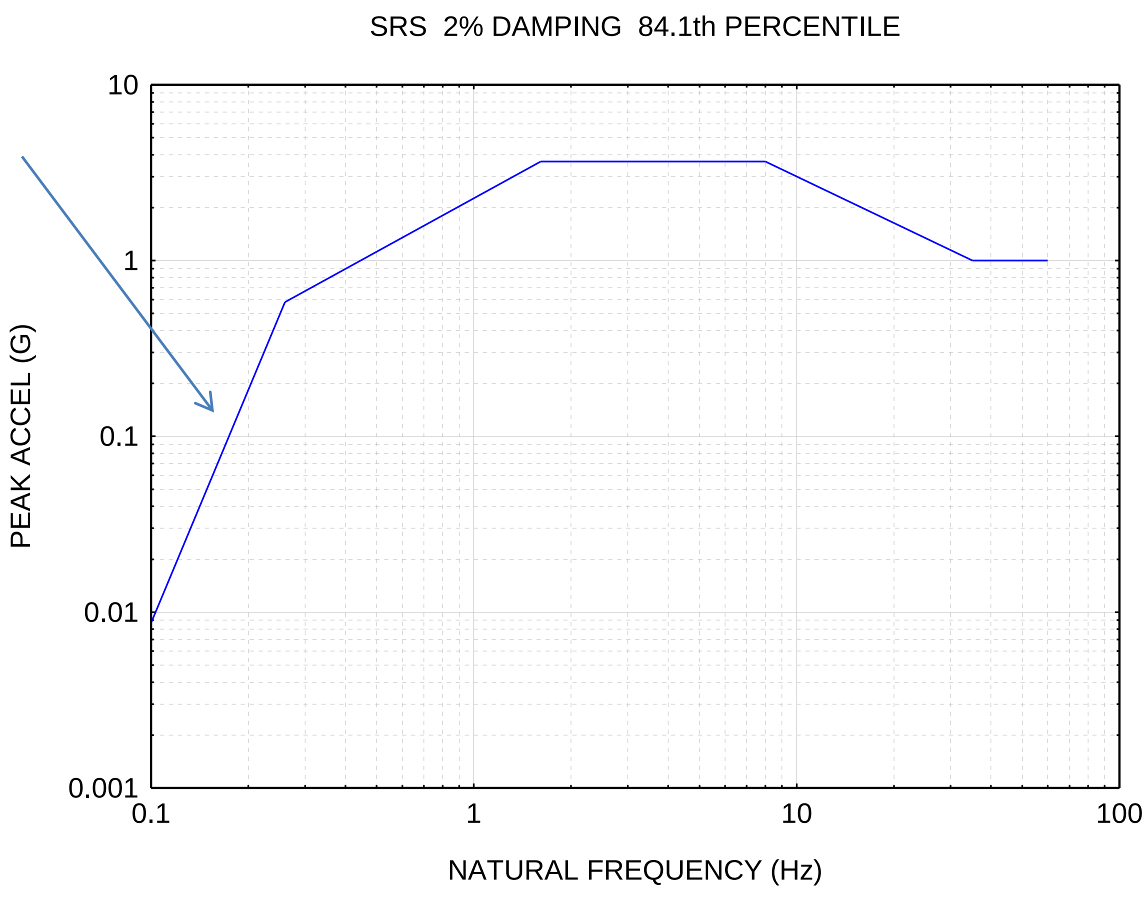
| Parameter | El Centro Synthesis | Alternate Synthesis |
|---|---|---|
| Energy E | 0.0589 | 0.01935 |
| Root energy amplitude Ae | 0.0731 | 0.04754 |
| Central time T (sec) | 13.56 | 9.687 |
| RMS duration D (sec) | 11.02 | 8.562 |
| Central skewness St(sec) | 10.21 | 11.06 |
| Normalized skewness S | 0.9267 | 1.291 |
| Central kurtosis Kt(sec) | 60.13 | 73.67 |
| Normalized kurtosis K | 5.455 | 8.604 |

The alternate synthesis has less energy and thus may cause an “under test” even though its SRS matches the specification.

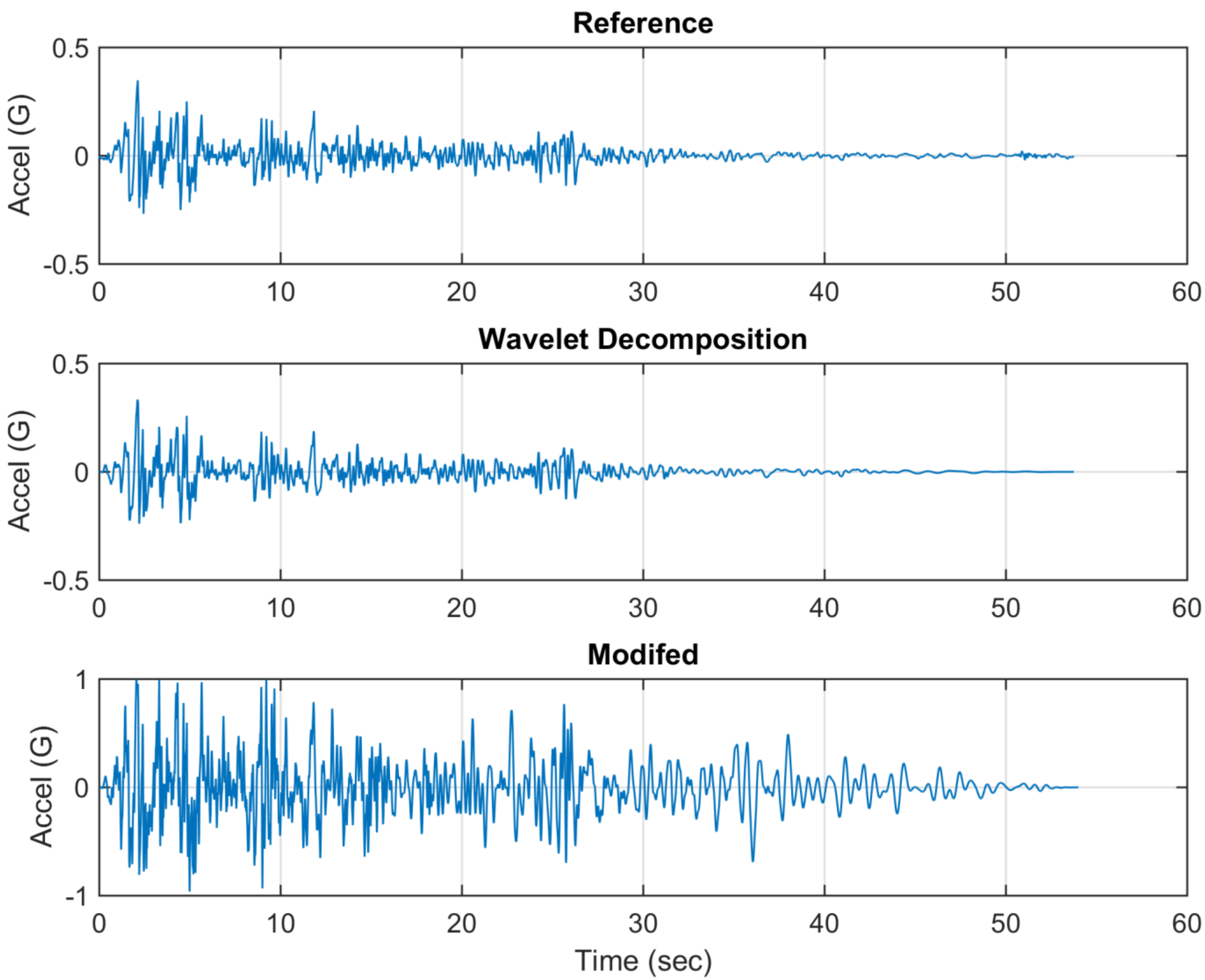
# Example 2

Steep slope is a challenge for time history

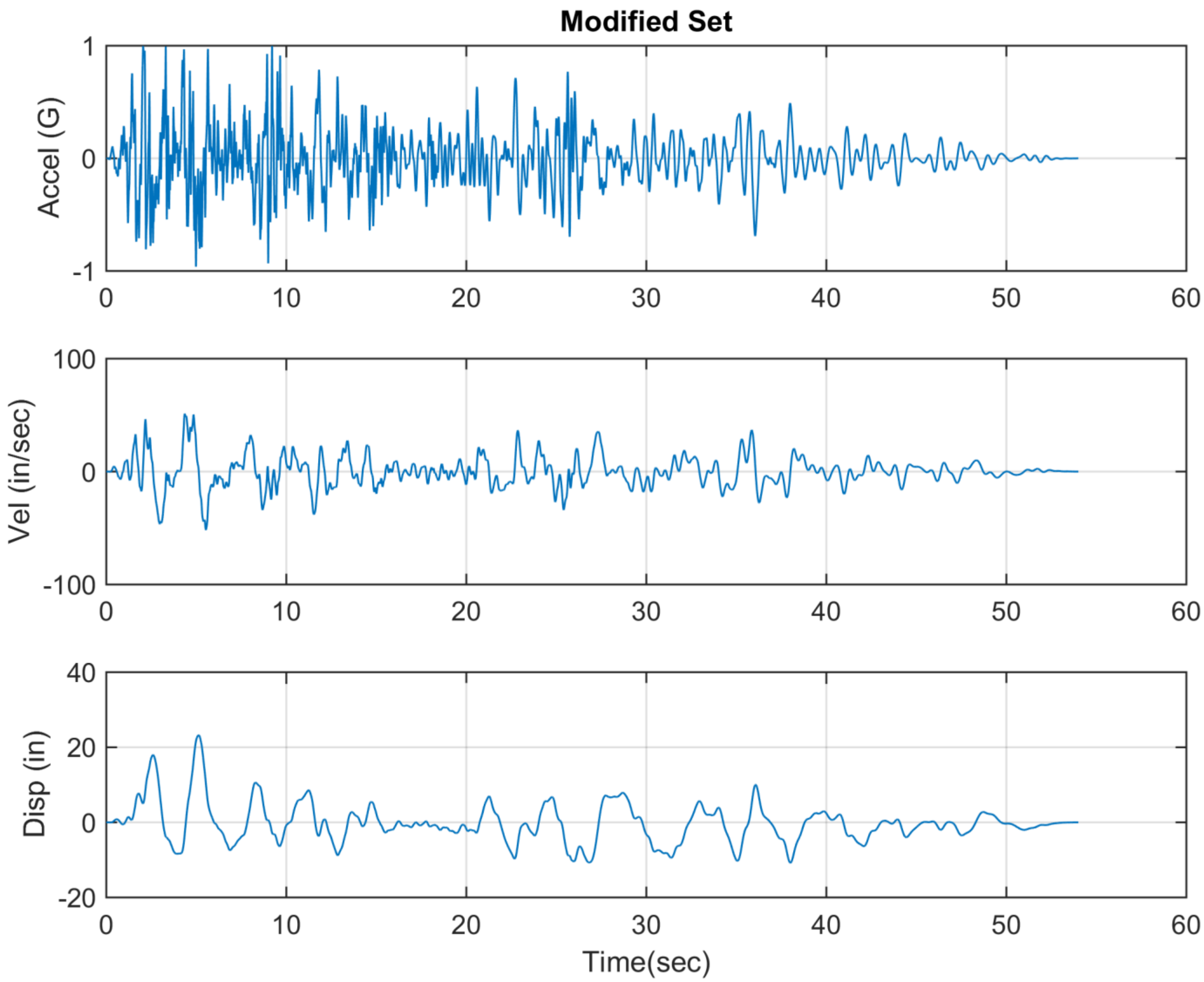
26.5 dB/octave

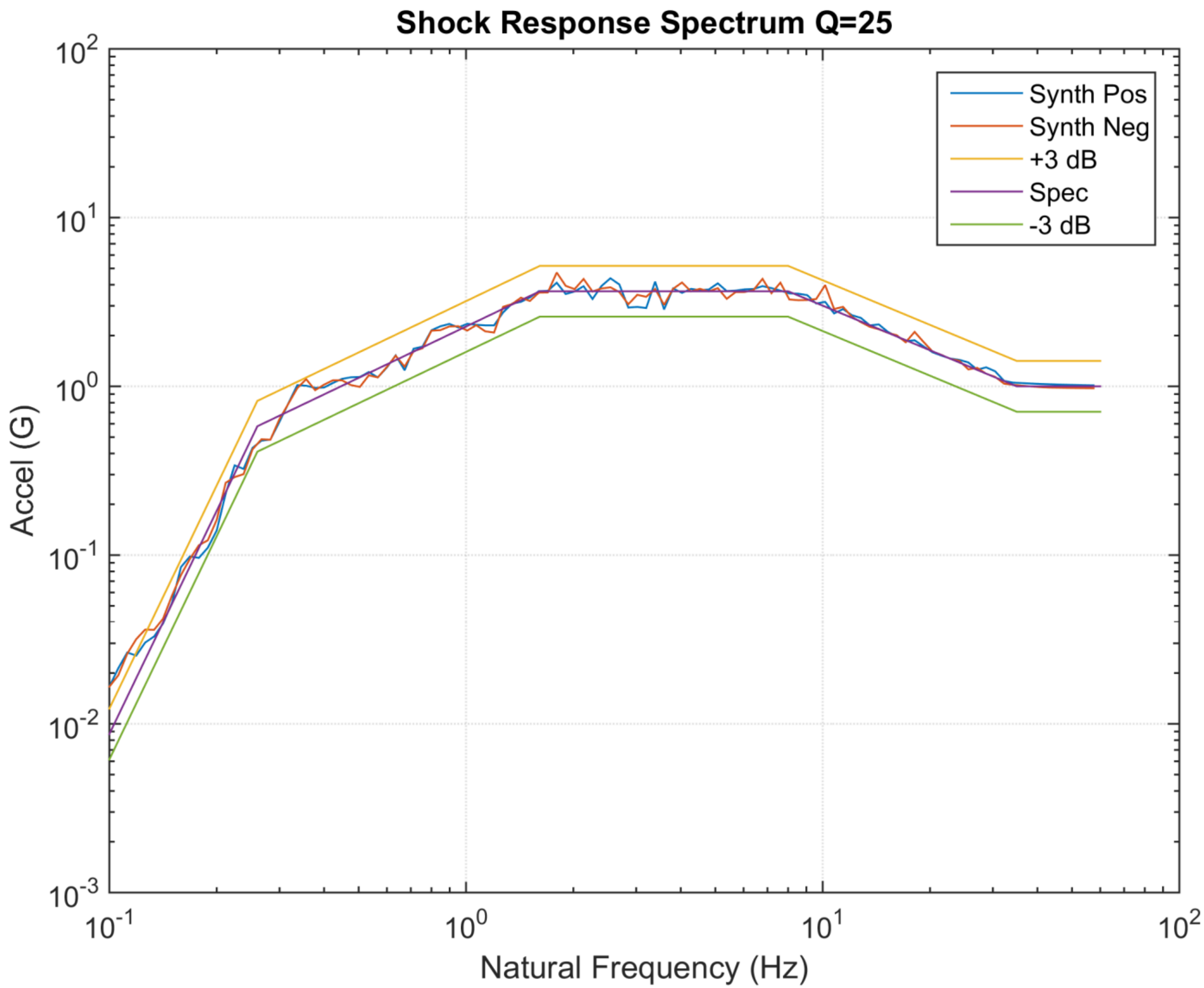



C. Harris, Shock and Vibration Handbook, Fourth Edition; W.J. Hall, Chapter 24, Vibrationdata of Structures Induced by Ground Motion, McGraw-Hill, New York, 1996.




- The El Centro NS data is again used as a basis
- The modified time history departs somewhat from the Reference in order to meet the SRS specification with its steep initial slope


Modified Set
Accel (G)
1
0
-1
0
10
20
30
40
50
60
Vel (in/sec)
100
0
-100
0
10
20
30
40
50
60
Disp (in)
40
20
0
-20
0
10
20
30
40
50
60
Time(sec)


Shock Response Spectrum Q=25
Synth Pos
Synth Neg
+3 dB
Spec
-3 dB
Accel (G)
Natural Frequency (Hz)
$10^{2}$
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-1}$
$10^{0}$
$10^{1}$
$10^{2}$