



**SEISMIC HAZARD ASSESSMENT AND SITE RESPONSE
ANALYSIS**

PART 3: FLING EFFECTS ON SOIL MOTIONS

Doyle Drive Replacement Project
San Francisco, California

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SEISMIC HAZARD ASSESSMENT AND SITE RESPONSE ANALYSIS PART 3: FLING EFFECT ON SOIL MOTIONS

Doyle Drive Replacement Project
San Francisco, California

1.0 INTRODUCTION

AMEC Geomatrix, Inc. (AMEC) prepared this ground motion study for the Doyle Drive Replacement Project, located in San Francisco, California. This report summarizes the development of the rock design response spectra, spectrum-compatible time histories, site response analyses and strain-compatible soil model parameters required for the seismic evaluation of the project site. This study was conducted in accordance with Subconsultant Agreement No. 131558/17 authorized by the Arup PB Joint Venture under the prime agreement No. 06/07-29.

The report is presented in three parts: Part 1: Seismic Hazard Assessment and Ground Motion Development; Part 2: Site Response Analysis; and Part 3: Fling Effects on Soil Motions. This report (Part 3: Fling Effects on Soil Motions) presents incorporation of fling effects in the fault parallel acceleration time histories of soil motion computed from the site response analyses presented in Part 2.

1.1 SUMMARY OF DESIGN GROUND MOTIONS, TIME HISTORIES AND SITE RESPONSE

Two levels of the rock design ground motions were presented in the Part 1 Seismic Hazard Analysis report, the Safety Evaluation Earthquake (SEE), and the Functionality Evaluation Earthquake (FEE). Response spectra were developed for two rock site conditions corresponding to shear wave velocities (V_{S30}) of 3,000 and 5,000 feet per second (ft/sec). Two horizontal components (Fault-normal, FN, and Fault-parallel, FP) of the SEE and FEE response spectra were developed to incorporate the near-fault directivity and polarity effects. Three sets of seed time histories (each set includes two horizontal and one vertical components) were identified for each design ground motion. As described in the Part 1 report, time domain spectral matching was performed to adjust these time histories to be compatible with their specified FN, FP and vertical response spectra.

Site response analyses were performed to compute variations of ground motion with depth and strain-compatible soil properties for use in the seismic soil-structure interaction analyses. The results of the site response analyses were presented in the Part 2 report. The spectrum-compatible time histories of the rock motions are used as rock input motions for site response

analyses presented in the Part 2 report. It is noted that the FP time histories used in the site response analyses were not modified to incorporate near-fault fling effects. It is believed that the fling effects will propagate rapidly through the soil profiles and will induce insignificant additional shear strains within the soil profiles (Abrahamson, 2009); therefore fault fling effects will not affect the strain-compatible soil properties estimated from the site response analyses performed for this study.

1.2 SCOPE OF WORK FOR MODIFICATION OF SOIL MOTIONS FOR FLING EFFECTS

The Part 3 report presents the procedure to incorporate near-fault fling effects on the soil motions computed from the site response analyses presented in the Part 2 report and the resulting soil motions.

1.3 ORGANIZATION OF REPORT

Section 2 of this report presents the procedure used to compute permanent tectonic deformation at the project site. Section 3 documents the modification of the fault-parallel acceleration time histories computed from the site response analyses to incorporate the near-fault fling effects. The near-fault fling effects are only applied to the SEE ground motions. Dr. Abrahamson (personal communication, 2009) indicated that the fling effects are insignificant for the FEE ground motion because the mean rupture distance for the FEE is larger than 20 km (Appendix A of Part 1 Report). Therefore, no modifications to account for fling effects were made to the FEE time histories.

2.0 GROUND MOTION DUE TO PERMANENT TECTONIC DEFORMATION

The movement of ground associated with the permanent offset of the ground (fling) often causes large long-period pulses, especially for a site located close to a fault. This fling-step is polarized onto the component parallel to the slip direction (FP component).

Abrahamson (2001) derived the equation of average slip on fault D_{fault} and the resulting equation is as follows:

$$\ln(D_{fault}) = 1.15M - 2.83 \quad (2-1)$$

where D_{fault} (cm) is the average displacement on the fault plane and M is the earthquake magnitude. Abrahamson (2001) assumed the attenuation of the amplitude of the fling to be a function of distance from the fault following the \cot^{-1} model. The tectonic displacement at a given site is as follows:

$$D_{site} = 0.5D_{fault} \cot^{-1}(\alpha R) / (\pi / 2) \quad (2-2)$$

where D_{site} (cm) is the tectonic displacement, R (km) is the rupture distance, and α is a constant parameter determined to be 0.22 (Abrahamson, 2001). The 0.5 factor implies the assumption of splitting the tectonic deformation equally to the two sides of the fault.

Since

$$\cot^{-1}(x) = \pi / 2 - \tan^{-1}(x) \quad (2-3)$$

Equation (2-2) results in:

$$D_{site} = D_{fault} (\pi / 2 - \tan^{-1}(\alpha R)) / \pi \quad (2-4)$$

Figure 1 presents the attenuation relationship of the normalized site displacement with respect to fault displacement as indicated by equation (2-4).

The functional form of the fling acceleration is assumed to be a single cycle of sine-wave with the amplitude and duration estimated empirically. The fling period (T_{fling}) is assumed to be a

function of magnitude of the earthquake as determined from the following relation (Abrahamson, 2001):

$$\ln(T_{fling}) = -6.96 + 1.15M \quad (2-5)$$

Dr. Abrahamson (2009) recently revised Equation (2-5) to incorporate the Denali fault earthquake as shown on Figure 2. For the mean magnitude of 7.6 corresponding to the 1000-yr return period earthquake, using T_{fling} calculated from Equation (2-5) is more conservative than that shown on Figure 2 [$T_{fling} = 5.92$ seconds from Equation (2-5) is slightly higher than 5.2 seconds shown on Figure 2]. The amplitude of the fling can be estimated using displacement at the site and the fling period (Abrahamson, 2001) as follows:

$$A(g) = \frac{D_{site} 2\pi}{981T_{fling}^2} \quad (2-6)$$

The fling is conservatively assumed to arrive at the time of the beginning of the large velocity pulse, t_1 , causing constructive interference between fling and the transient displacement of the spectrum compatible ground motion. The acceleration response spectrum of the time history that includes the effects of fling should envelop that of the original time history.

3.0 DEVELOPMENT OF FAULT PARALLEL ACCELERATION TIME HISTORIES

3.1 INPUT PARAMETERS FOR SEE

For the Doyle Drive Replacement Project, the parameters to determine fling acceleration time history are magnitude and rupture distance of 7.6 and 13 km, respectively. These parameters were taken from deaggregation of 1,000 year return period at PGA and $T = 1$ sec, as shown on Figure 3 and Figure 4.

3.2 METHOD

Following Abrahamson (2002), the procedure to develop the time history that include fling effects are:

- Determine fling parameters including fling period (T_{fling}) and amplitude (A) from equations (2-1) and (2-4) to (2-6), as described in previous sections.
- Determine fling arrival time t_f and polarity such that the fling velocity will constructively interfere with the velocity from the transient time history.
- Compute fling acceleration time history by assuming a single cycle of sine-wave form.
- Compute the total fault-parallel ground motion by adding fling time history to acceleration time history computed from site response analyses.
- Compute the spectrum of the total fault-parallel ground motion; this should envelop that of the original time history.

3.3 RESULTS FOR SEE

Incorporation of fling effects was completed for three profiles in the Battery tunnels area, two profiles in the Main Post tunnels area, and two profiles in the Retaining Wall No. 8 area. Three earthquakes including 1990 Manjil Earthquake, 1999 Kocaeli Earthquake, and 1999 Chi-Chi Earthquake, were analyzed for each profile. Horizontal time histories of the fault parallel component, from site response analyses at selected depths for each profile were modified to include fling effects.

Figure 5 to Figure 238 present the original time histories, fling time histories, modified time histories, and acceleration and displacement response spectra. These figures show that the arrival time of the fling was chosen to constructively interfere with the original time histories. Response spectra of the modified time histories envelop those of original time histories.

4.0 REFERENCES

Abrahamson, N.A., (2001) "Development of Fling Model for Diablo Canyon ISFSI," Pacific Gas and Electric Company, Geosciences Department, Calc. No. GEO.DCPP.01.12.

Abrahamson, N.A., (2002) "Development of 5 sets of Faults Parallel Acceleration Time Histories That Include the Effects of Fling for the DCPP ISFSI," Pacific Gas and Electric Company, Geosciences Department, Calc. No. GEO.DCPP.01.14.

FIGURES

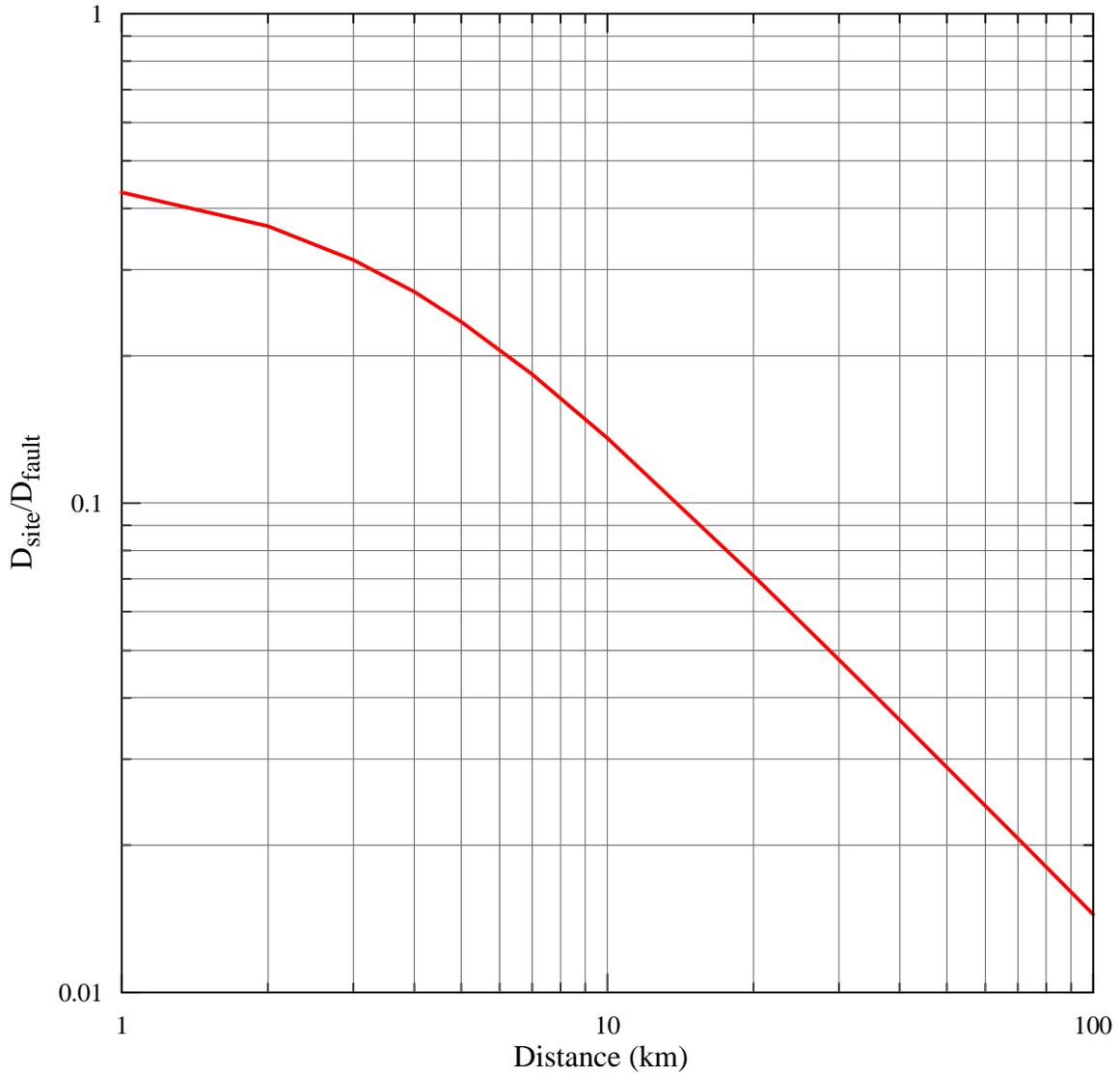


Figure 1: Attenuation relationship of fling displacement with distance (normalized by the estimated fault displacement) used in the present study

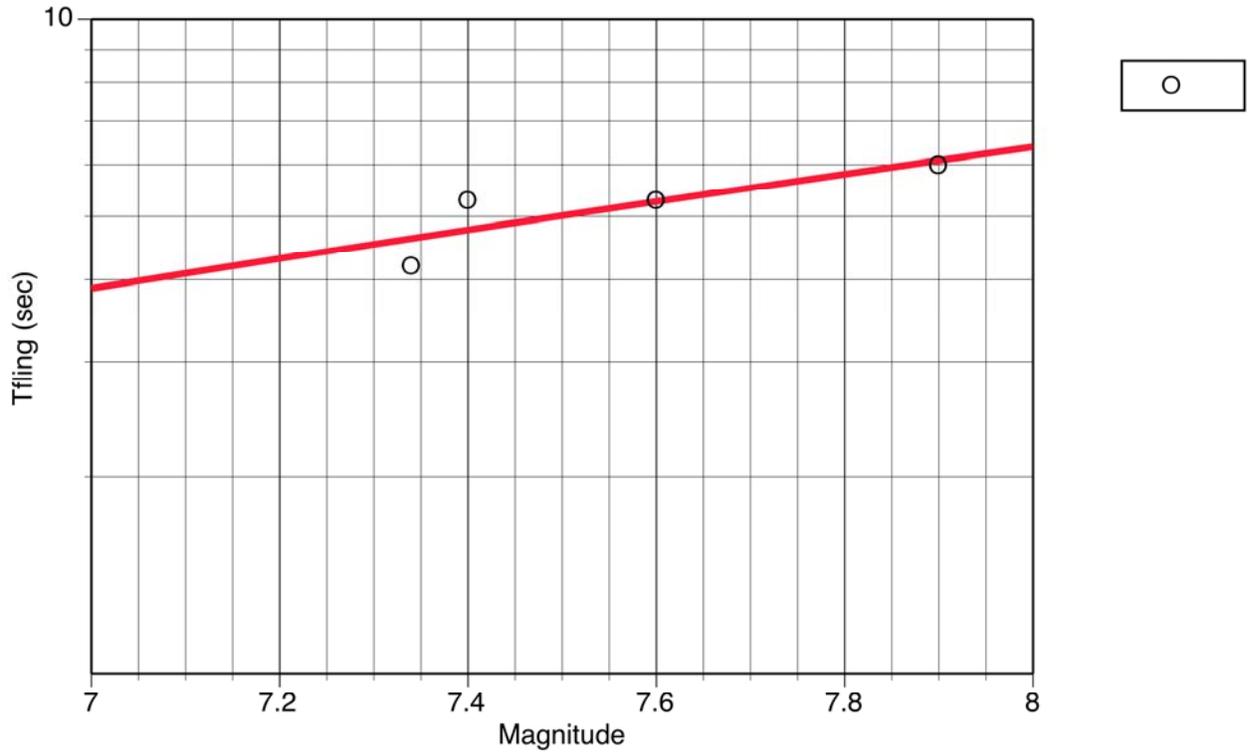


Figure 2: Fling period as a function of magnitude (recently revised by Abrahamson on May 5, 2009 from the original Figure 6-9 of Abrahamson, 2001 to incorporate the Denali fault earthquake)

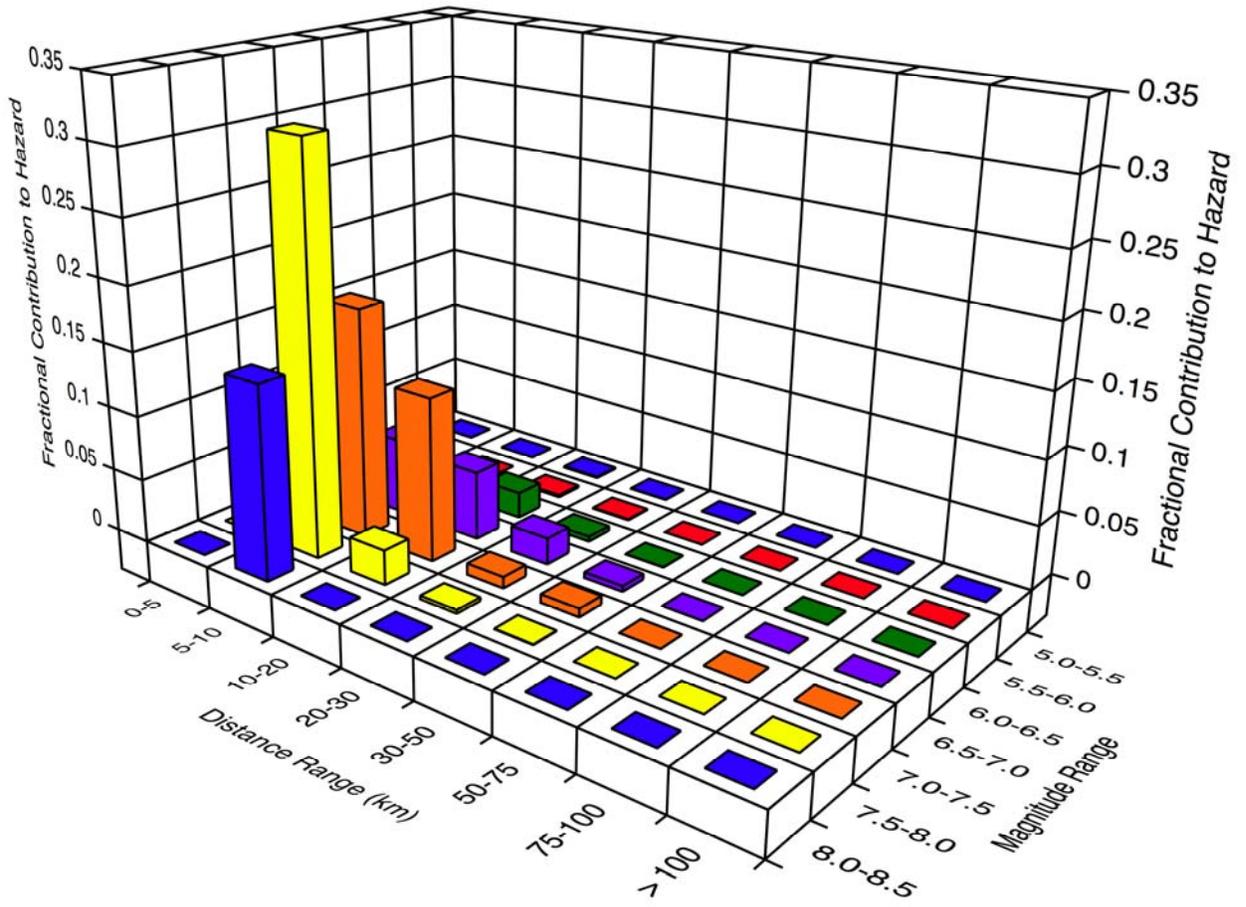


Figure 3: Deaggregation for 1,000 year return period: PGA

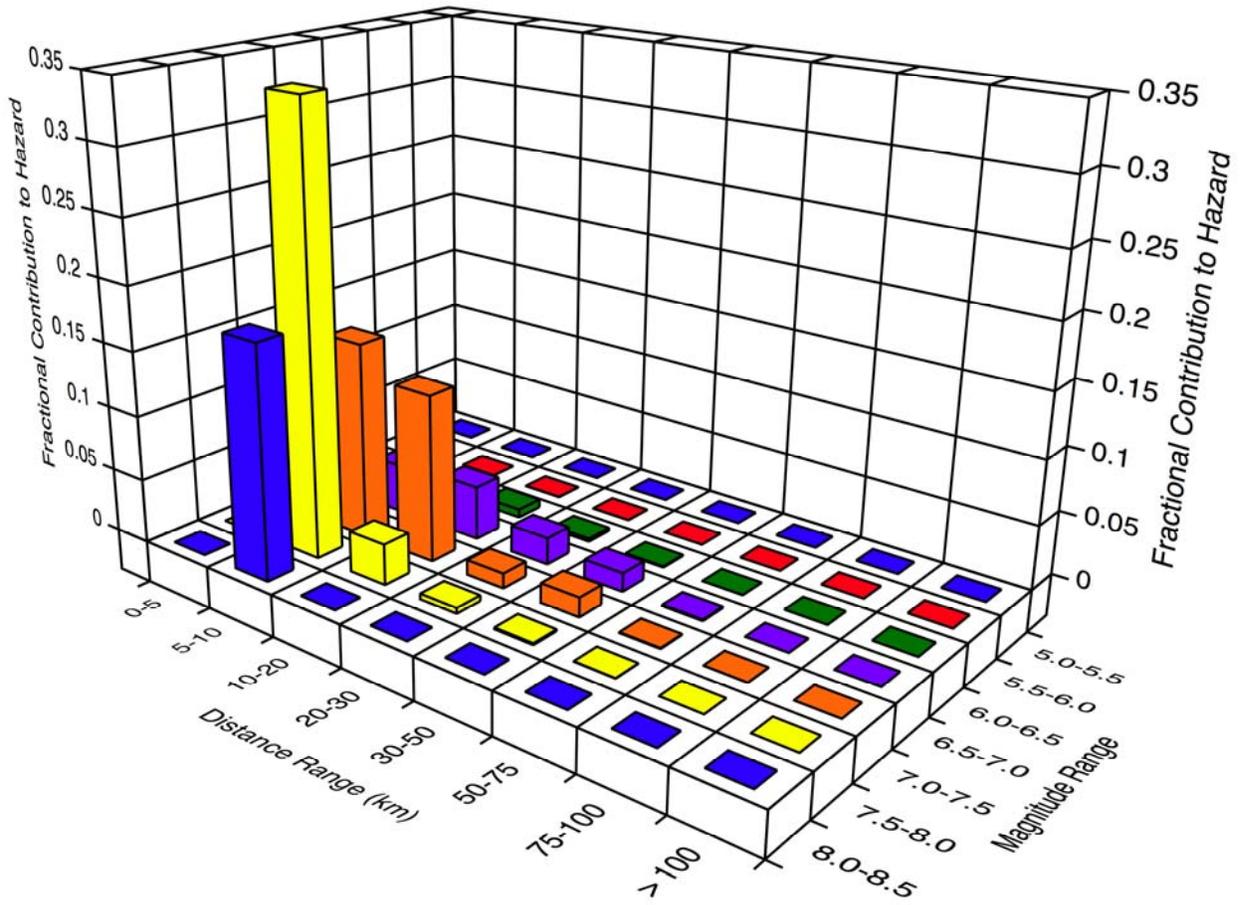


Figure 4: Deaggregation for 1,000 year return period: T=1 sec

EAST BATTERY TUNNELS (DEEP) PROFILE

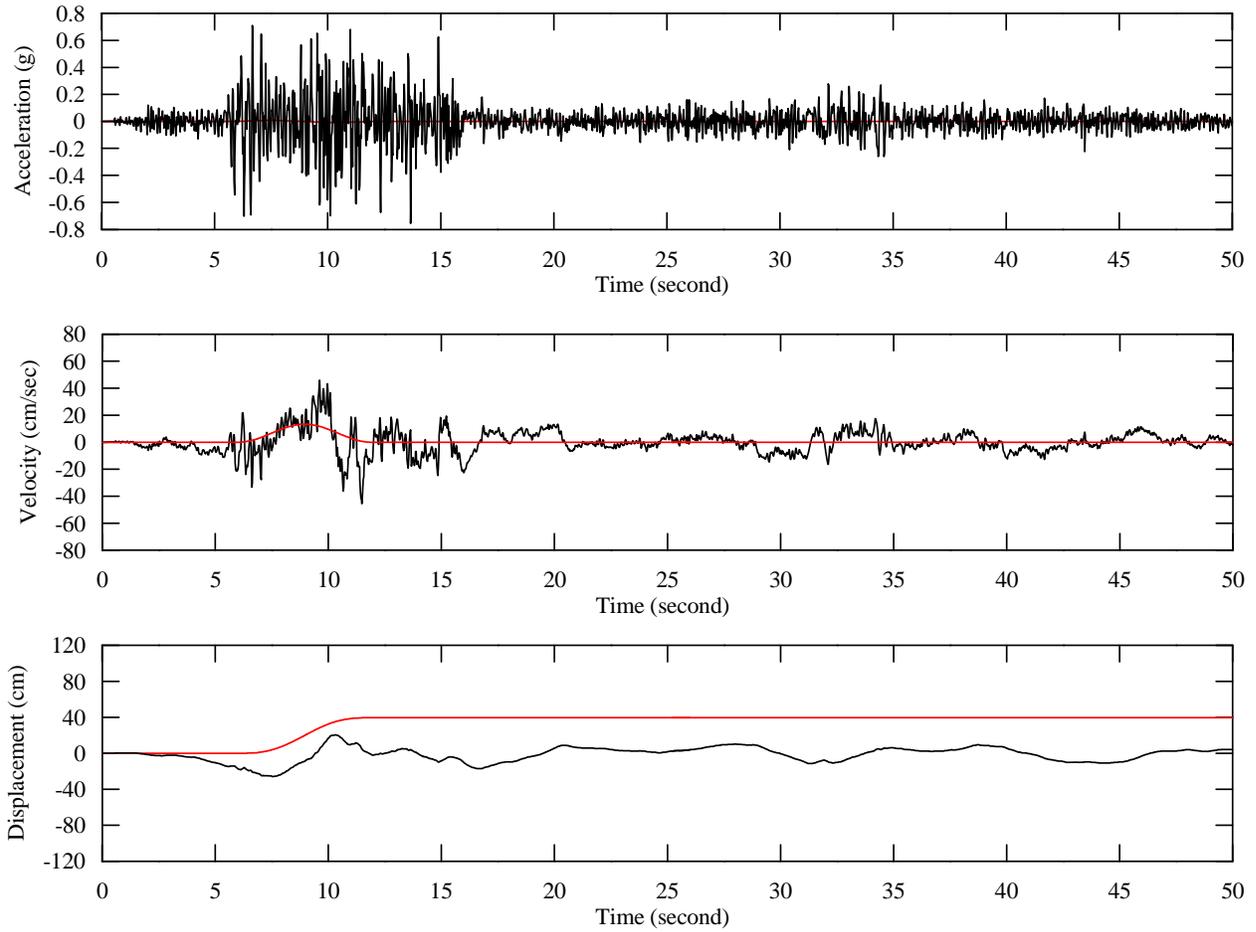


Figure 5: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1990 Manjil Earthquake

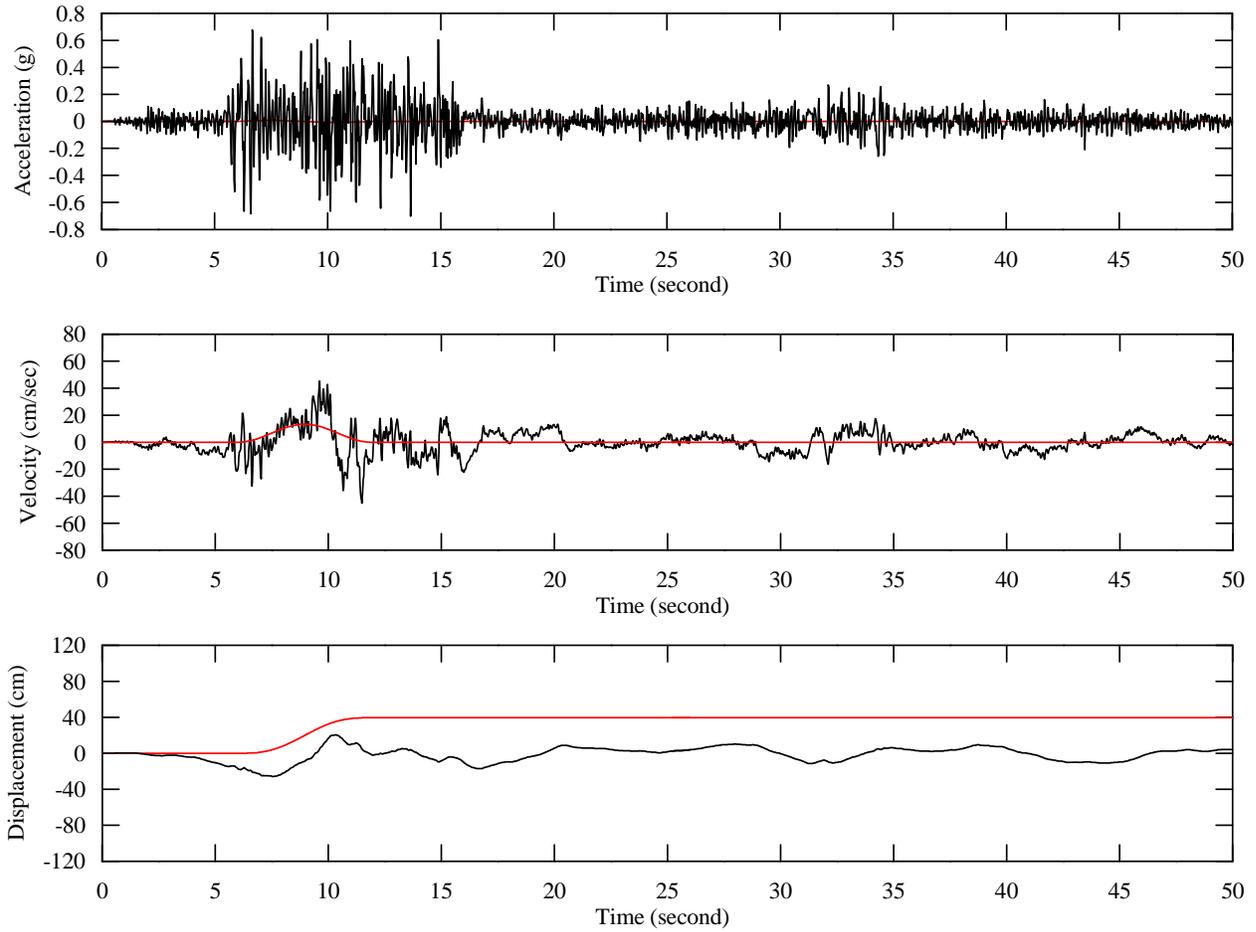


Figure 6: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1990 Manjil Earthquake

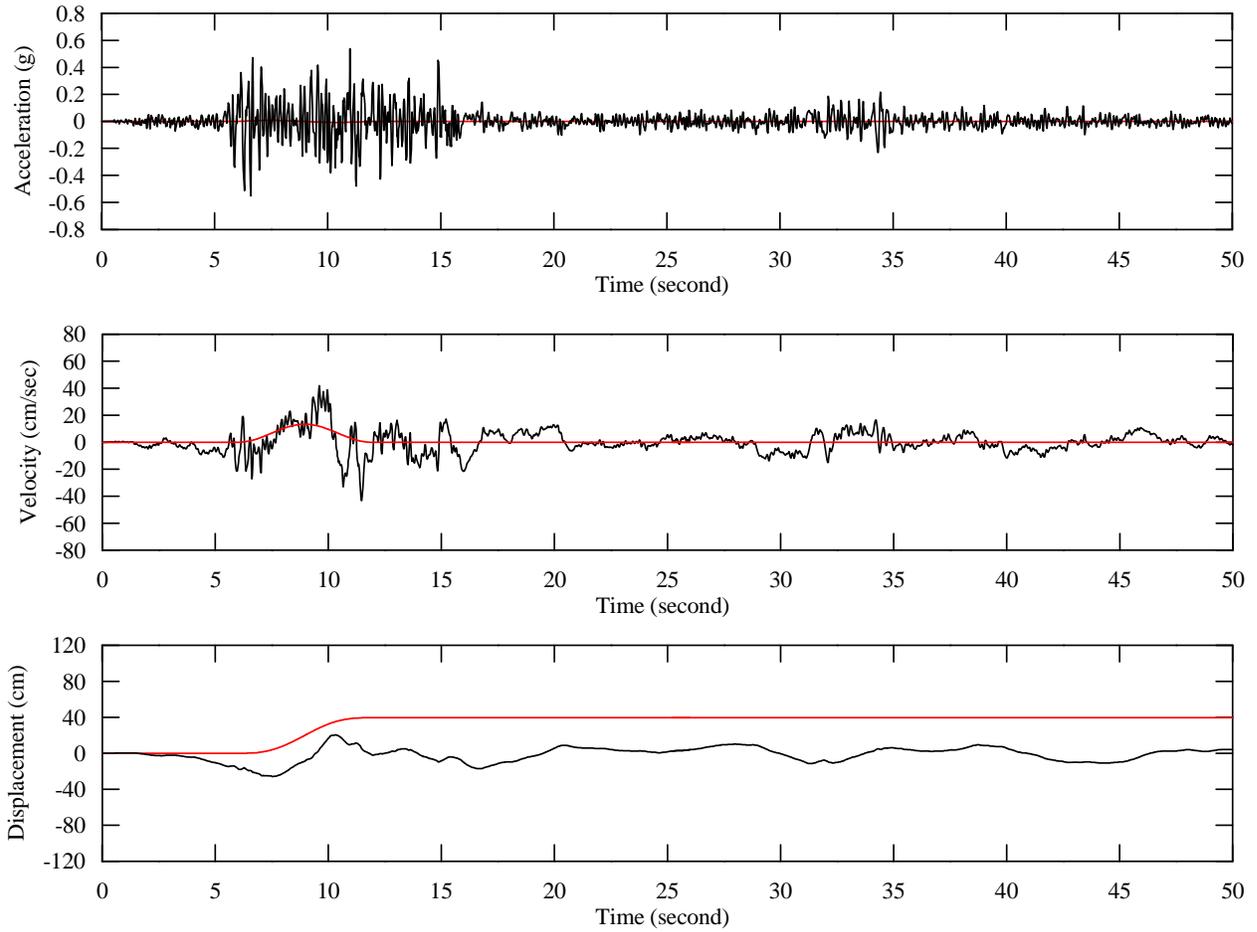


Figure 7: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1990 Manjil Earthquake

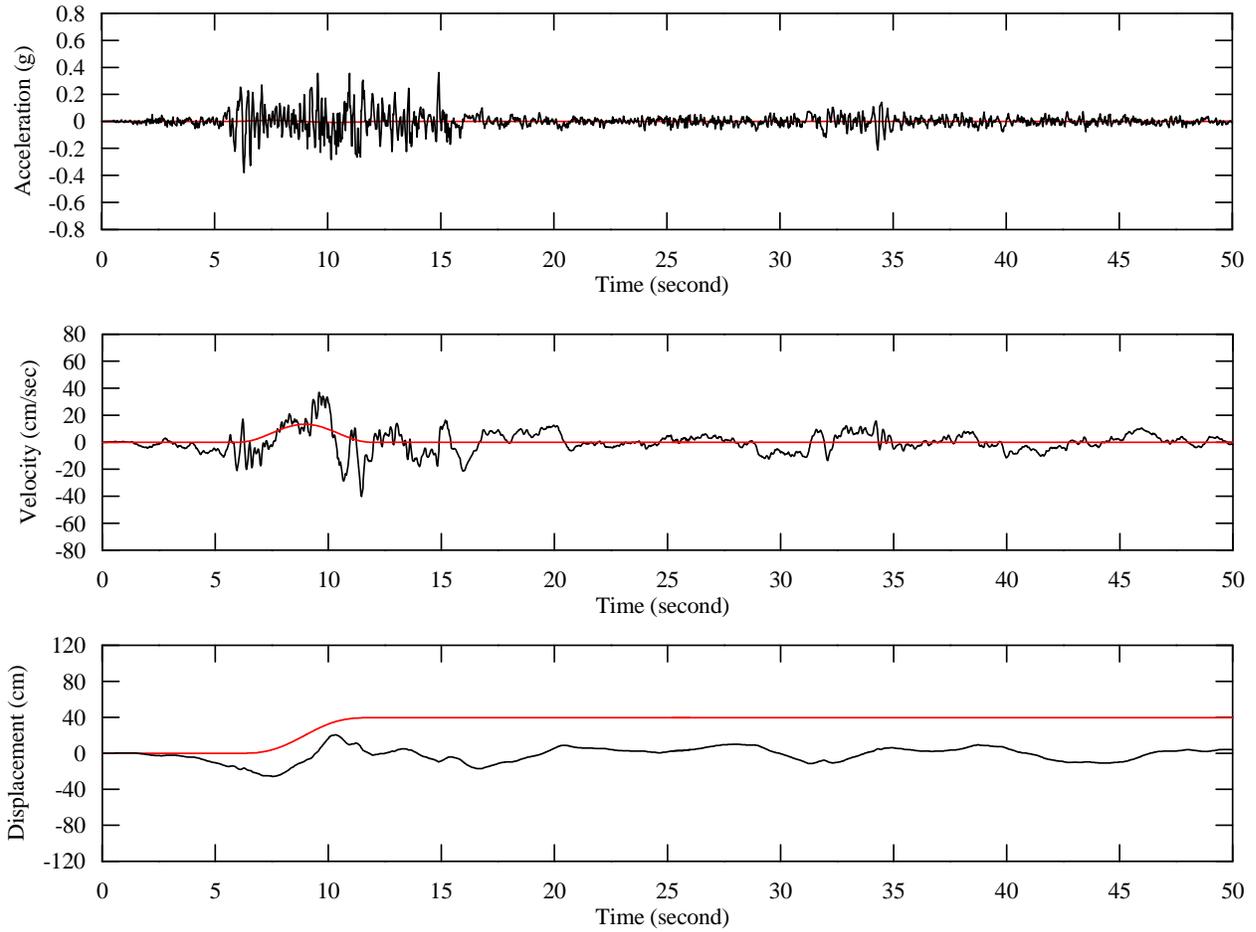


Figure 8: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1990 Manjil Earthquake

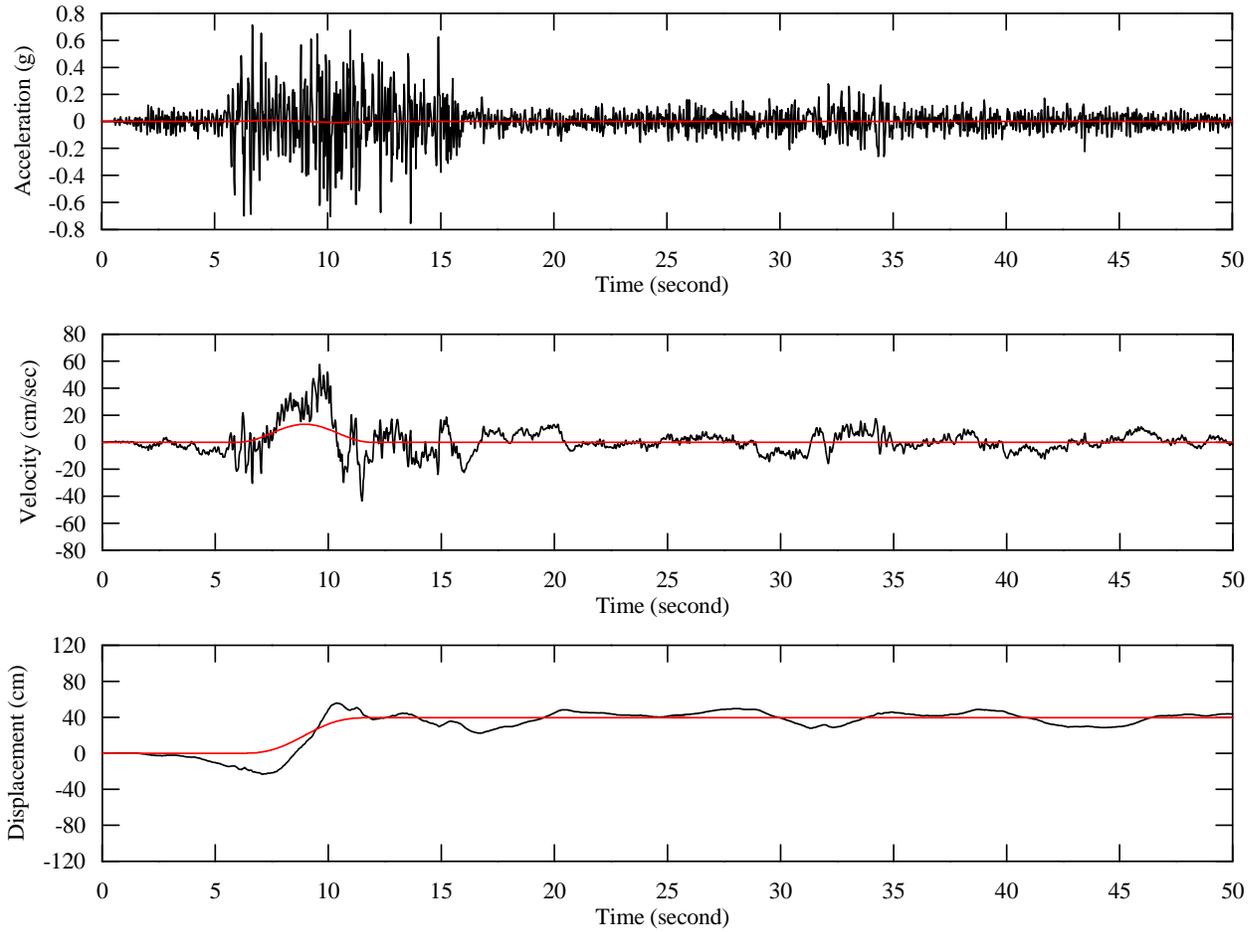


Figure 9: Fault parallel time histories including fling at ground surface, 1990 Manjil Earthquake

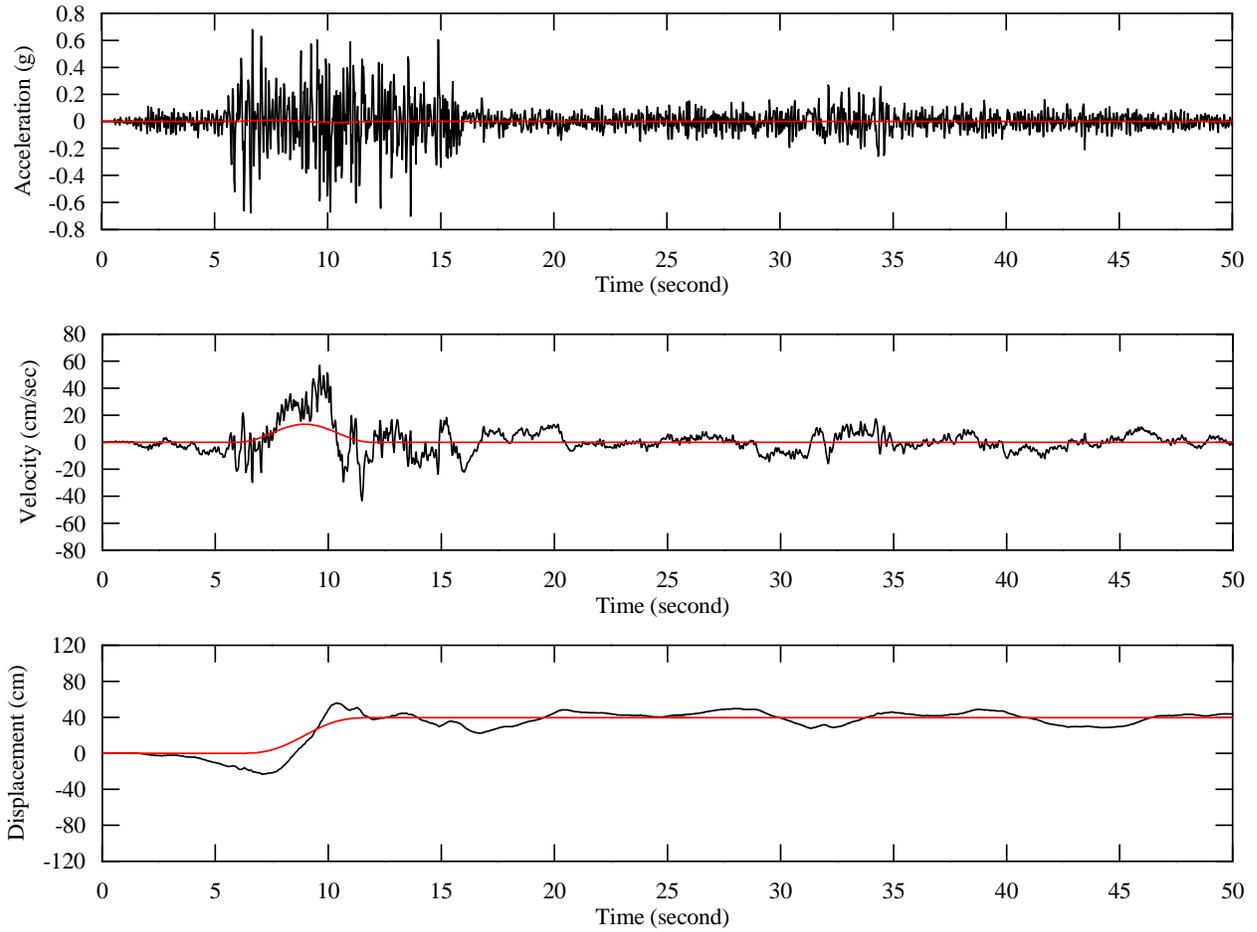


Figure 10: Fault parallel time histories including fling at crown of the tunnel, 1990 Manjil Earthquake

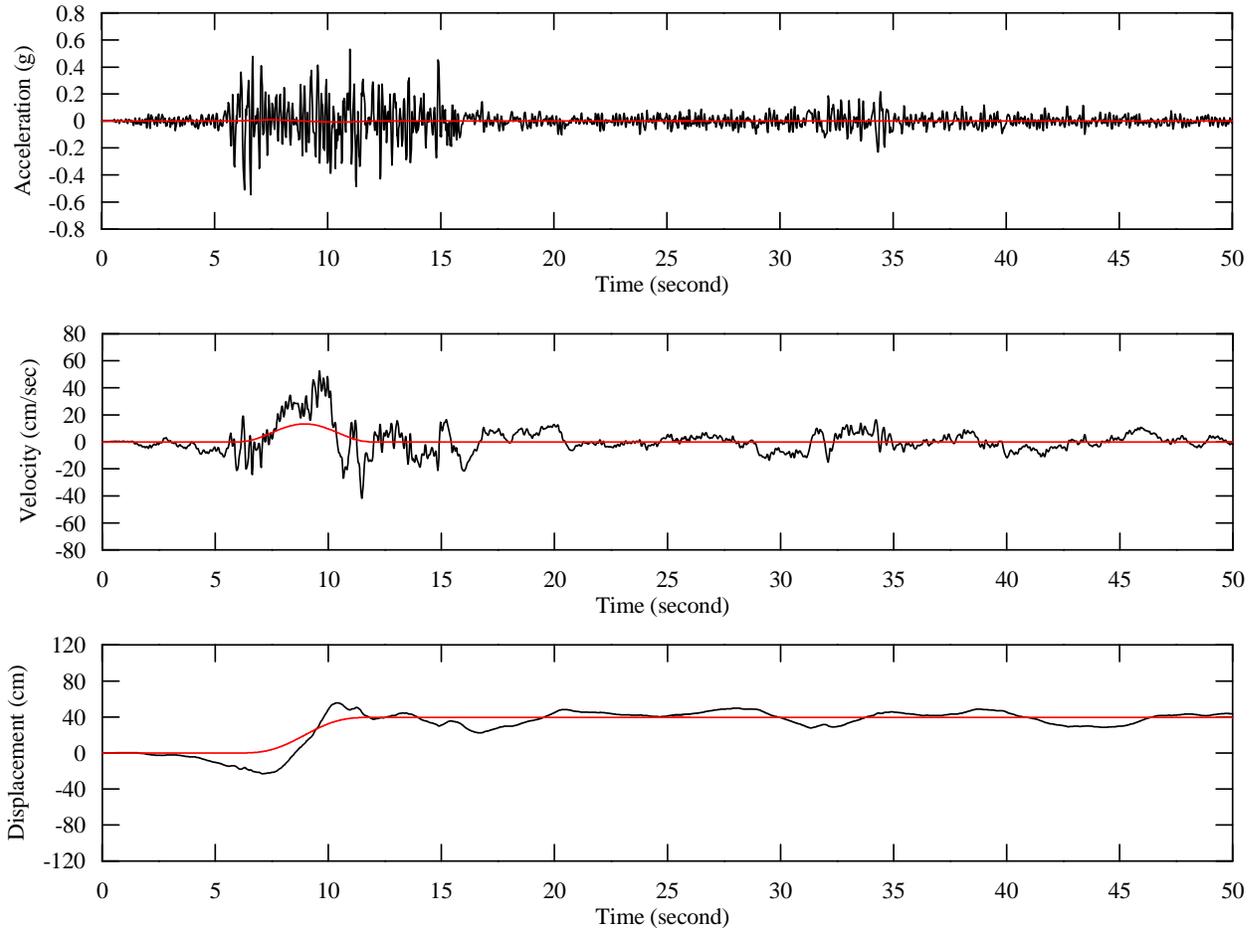


Figure 11: Fault parallel time histories including fling at top of side wall, 1990 Manjil Earthquake

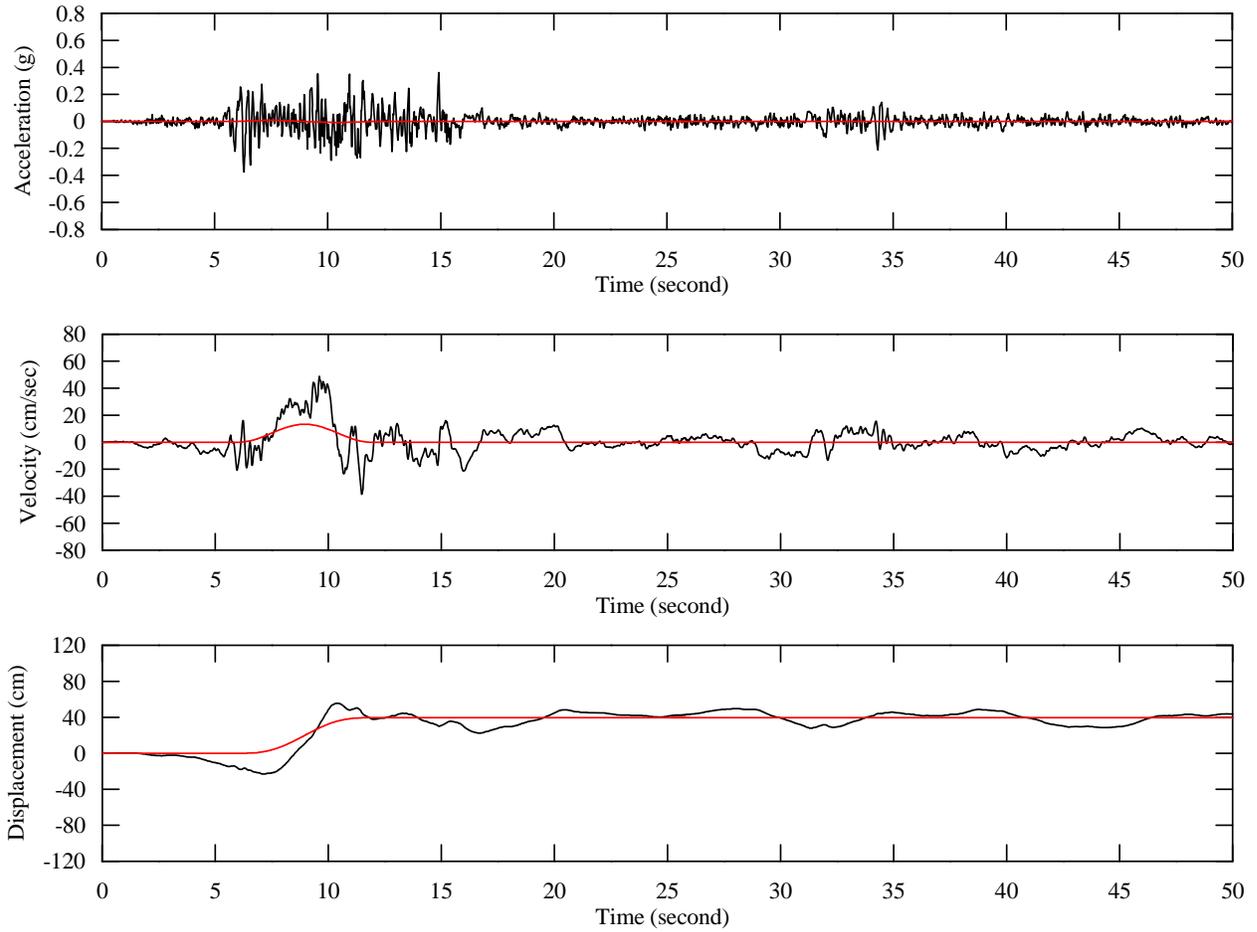


Figure 12: Fault parallel time histories including fling at invert of the tunnel, 1990 Manjil Earthquake

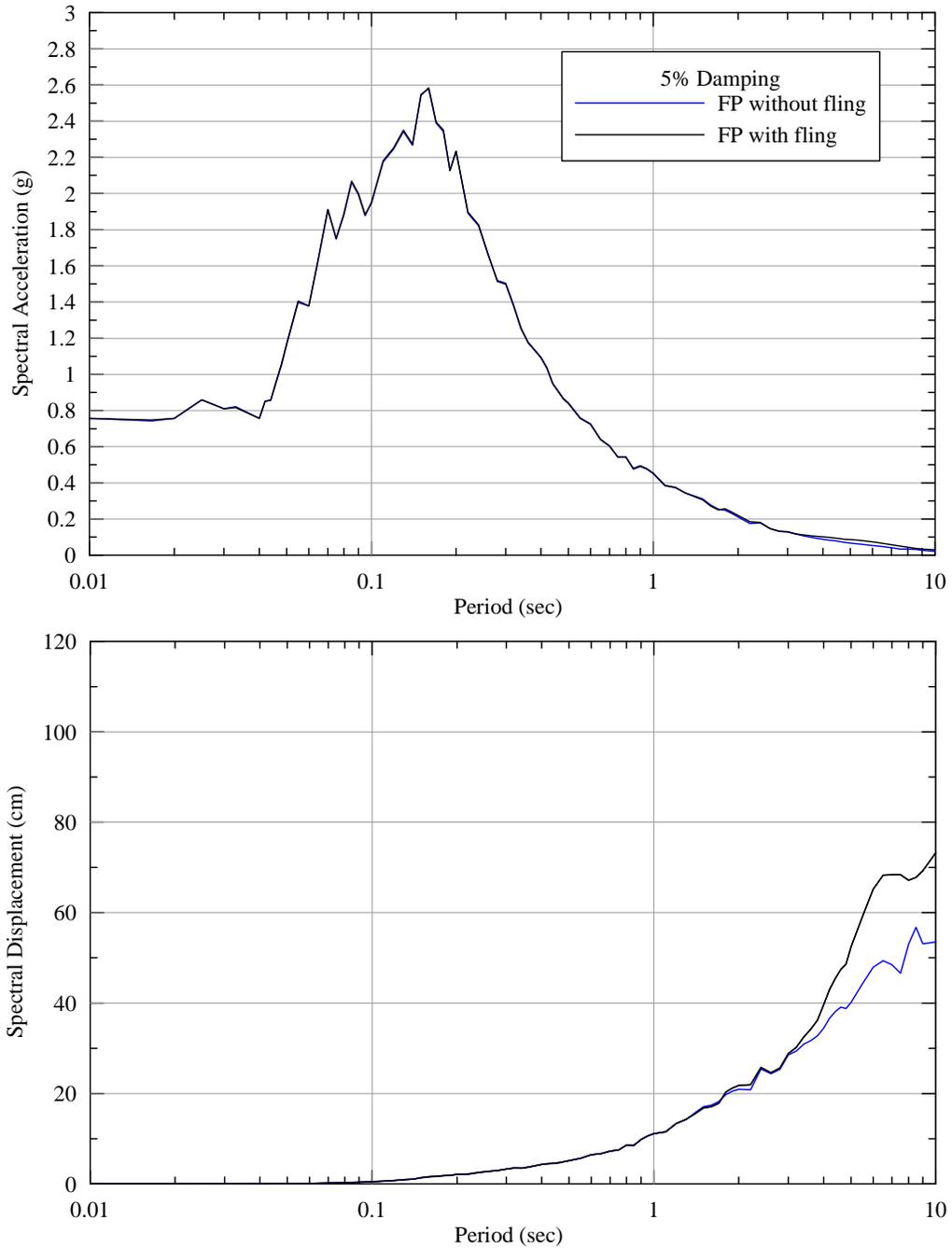


Figure 13: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1990 Manjil Earthquake

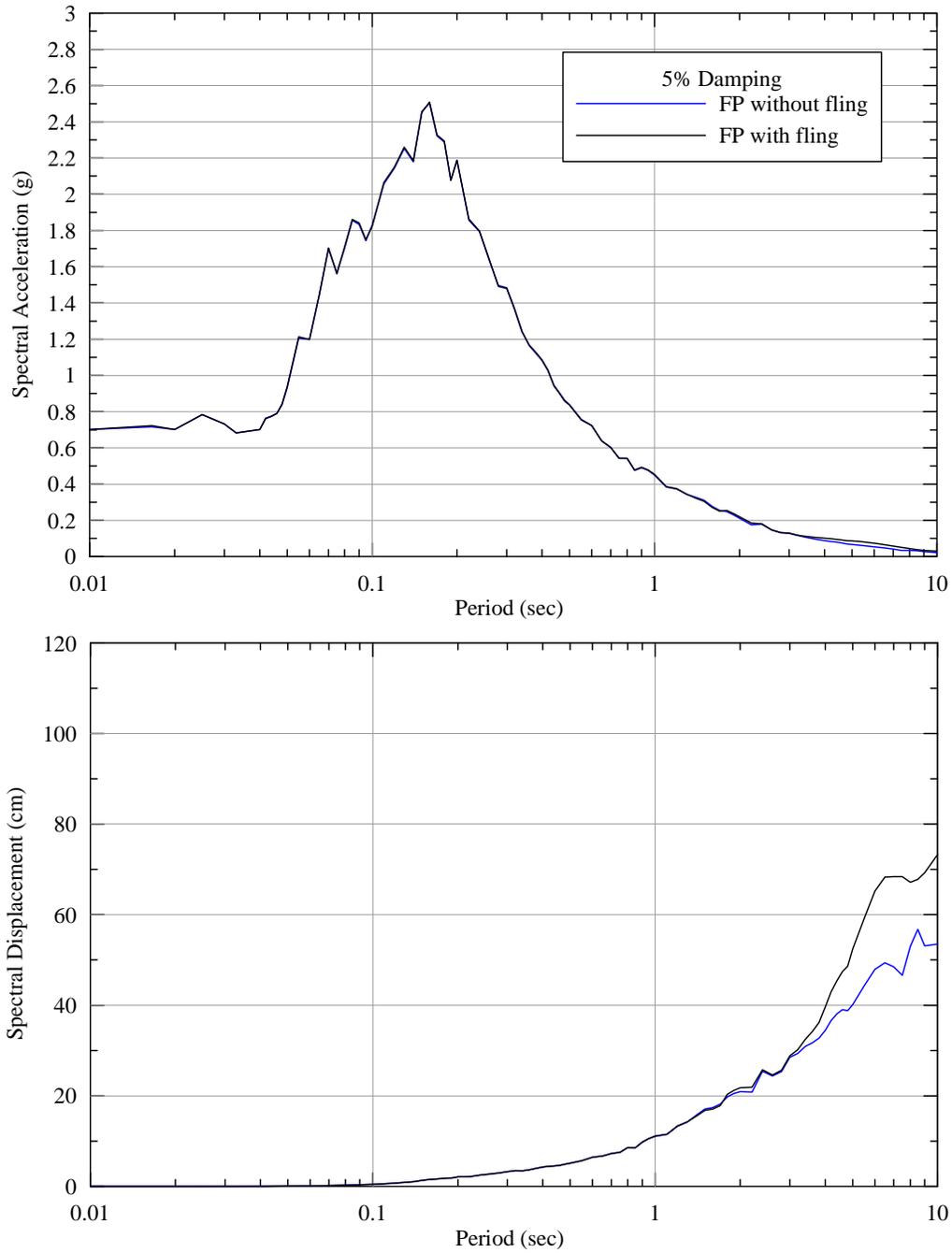


Figure 14: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1990 Manjil Earthquake

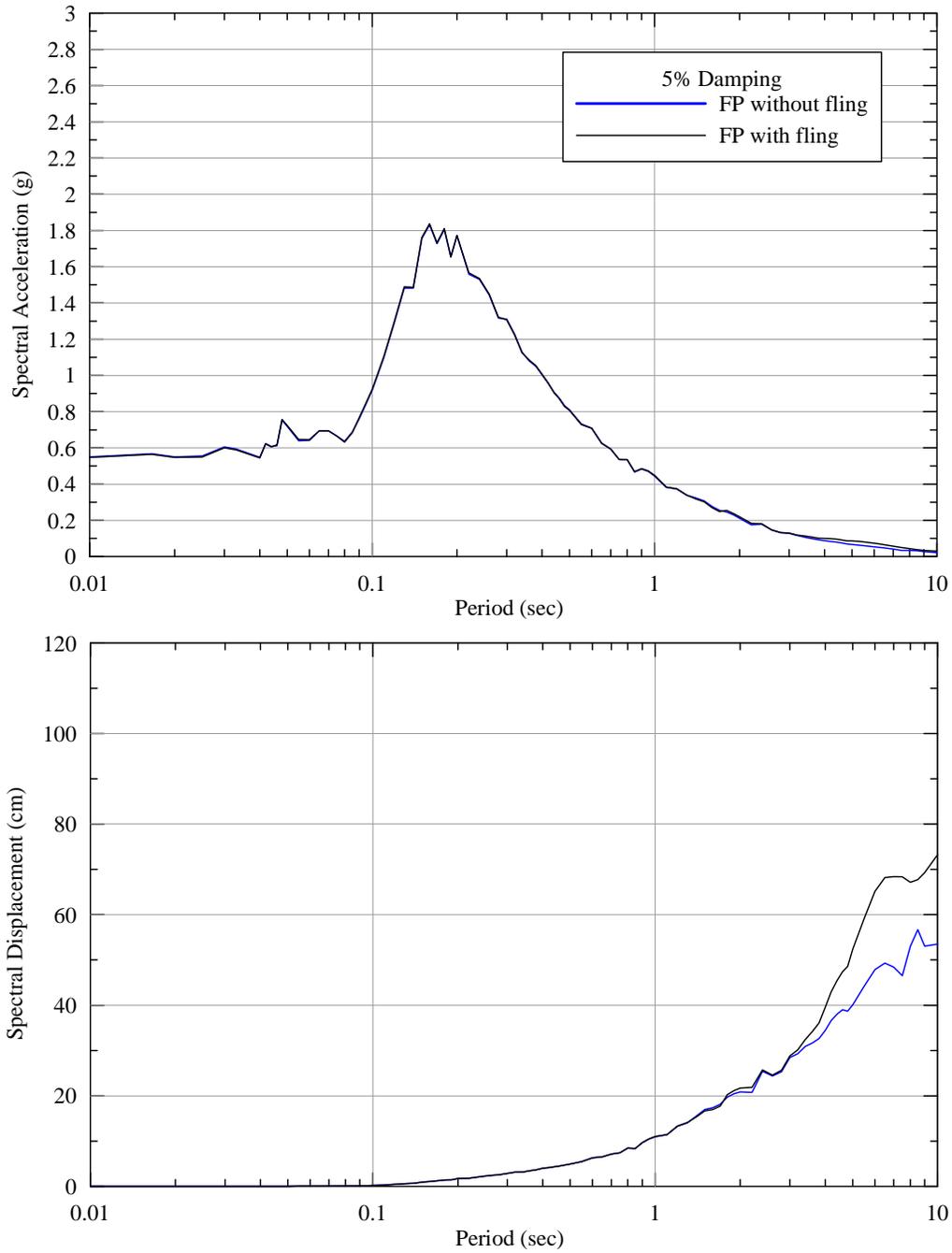


Figure 15: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1990 Manjil Earthquake

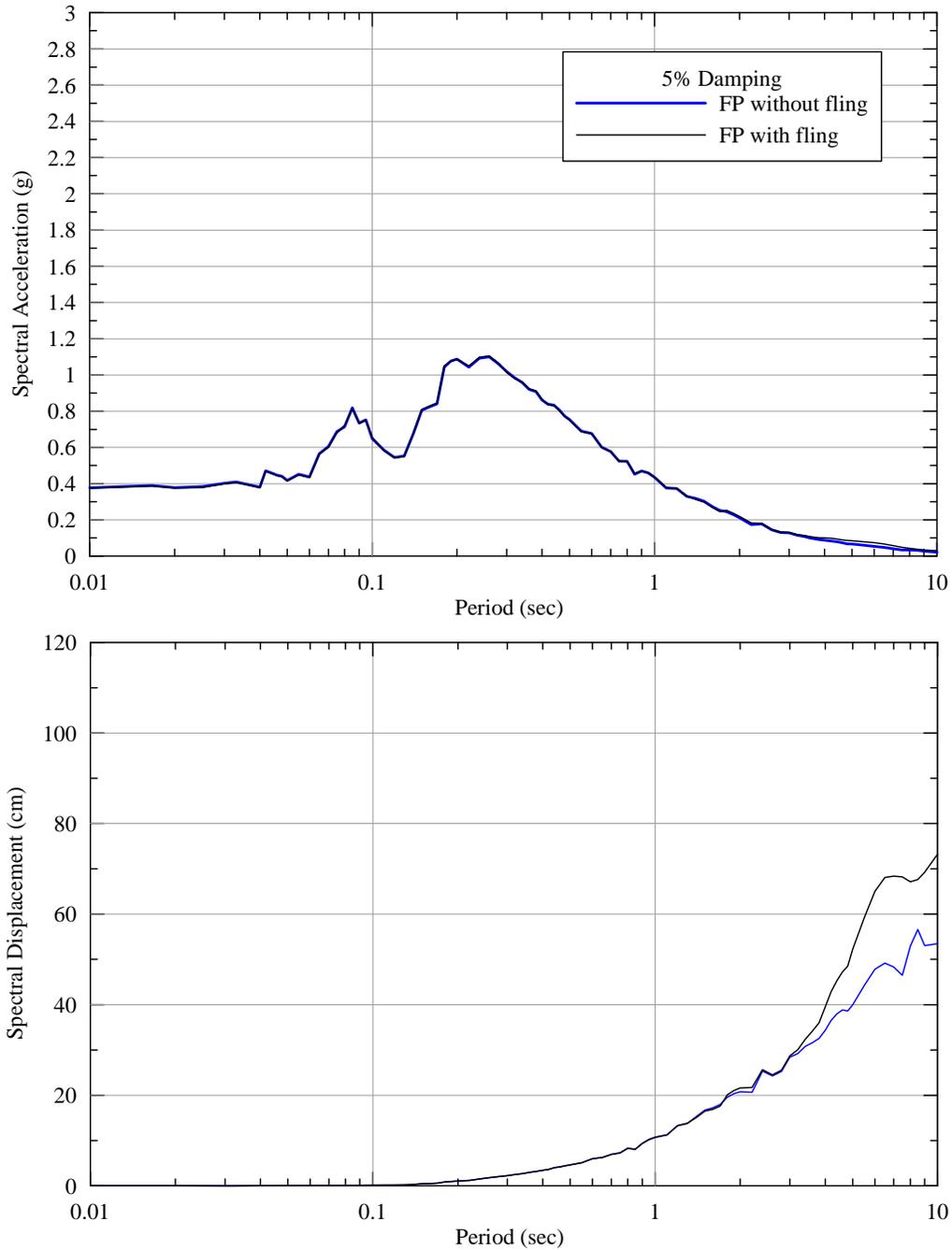


Figure 16: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1990 Manjil Earthquake

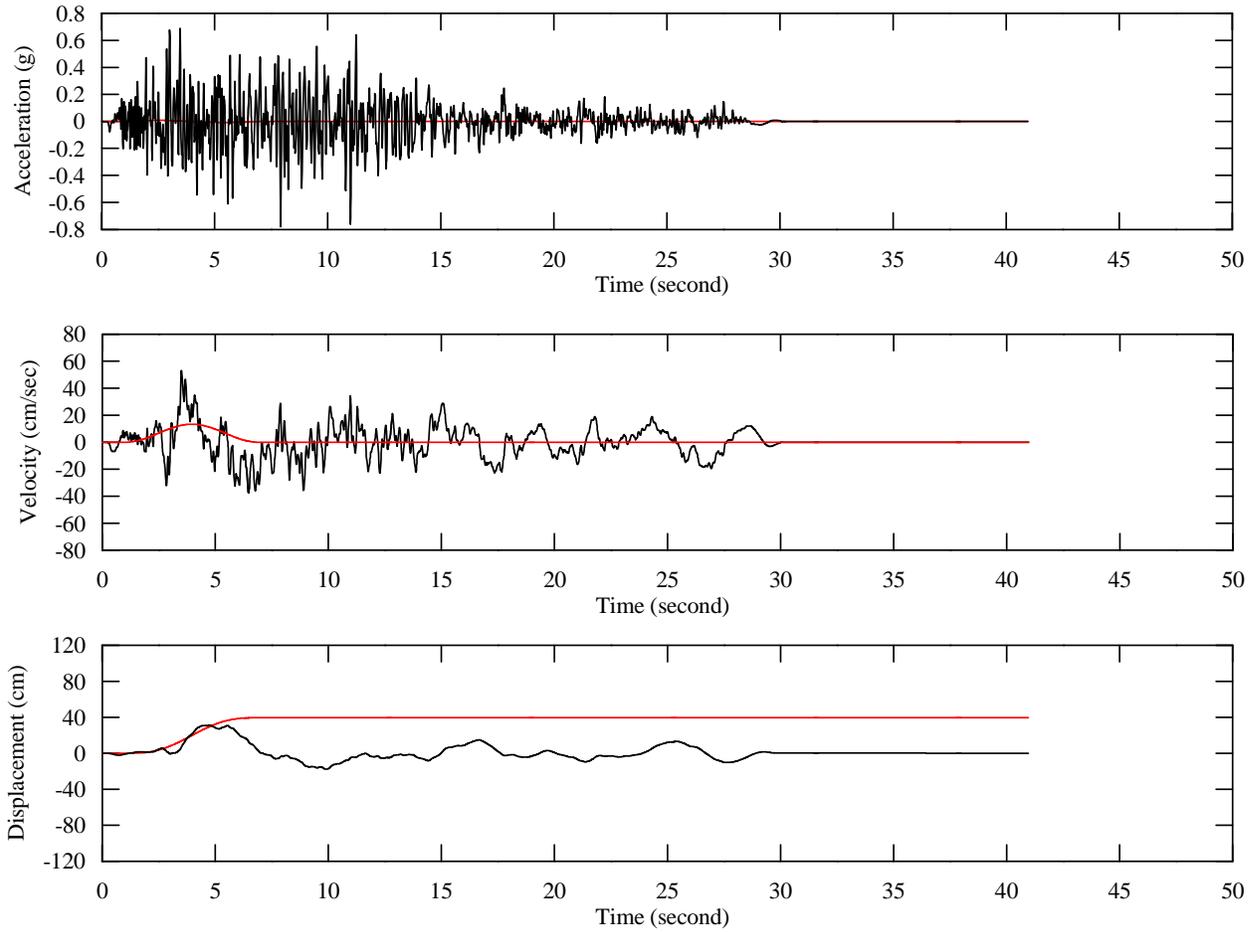


Figure 17: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1999 Kocaeli Earthquake

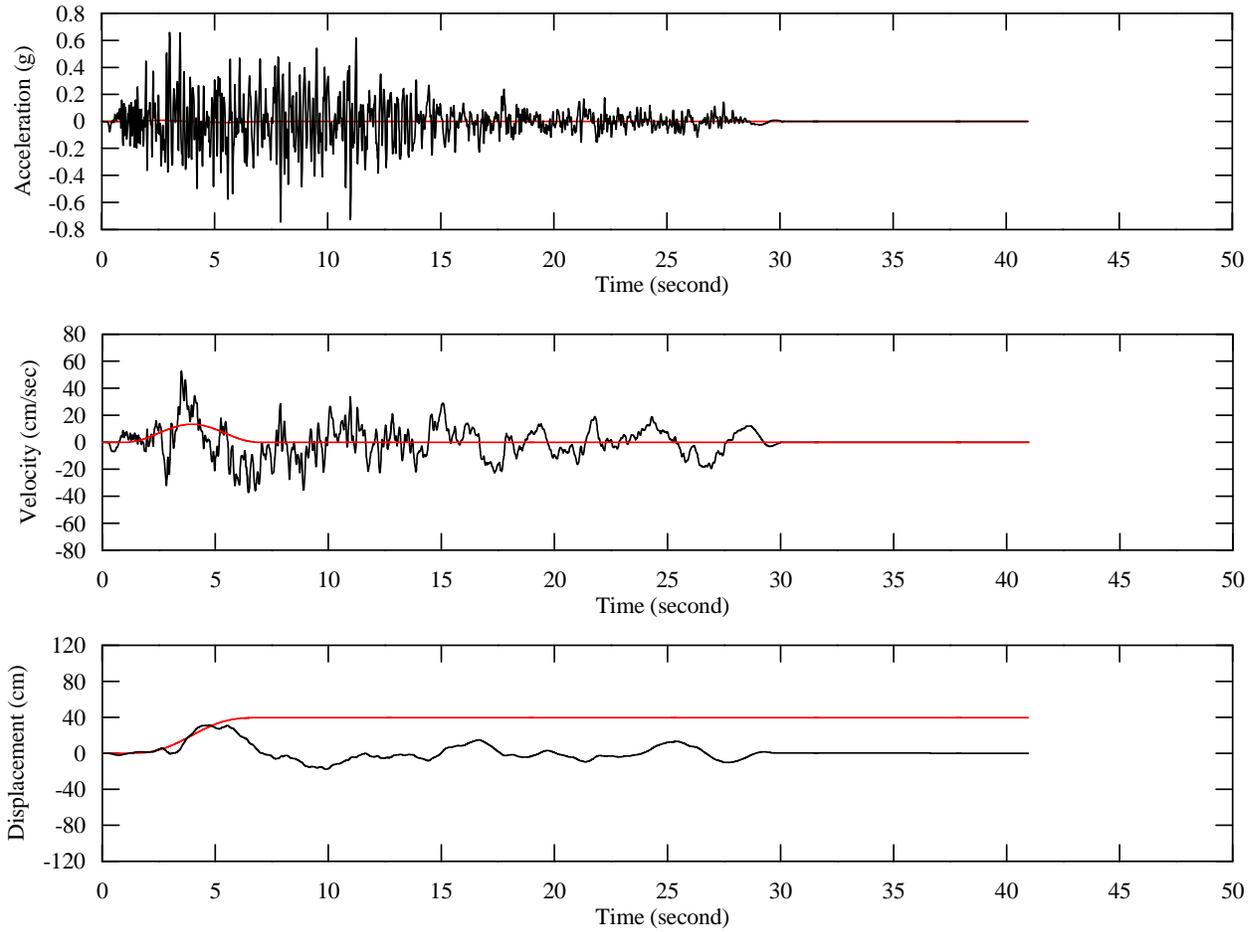


Figure 18: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1999 Kocaeli Earthquake

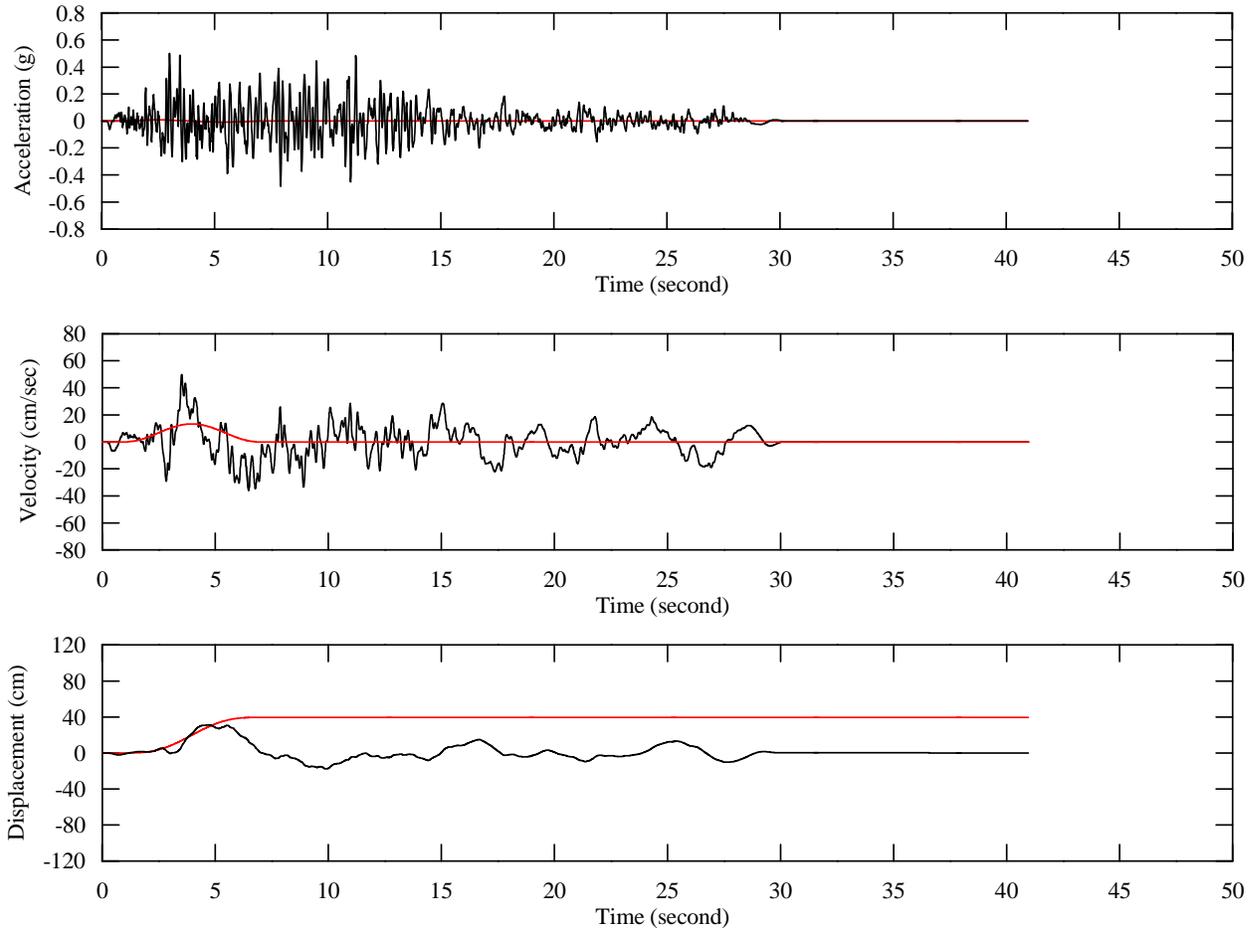


Figure 19: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1999 Kocaeli Earthquake

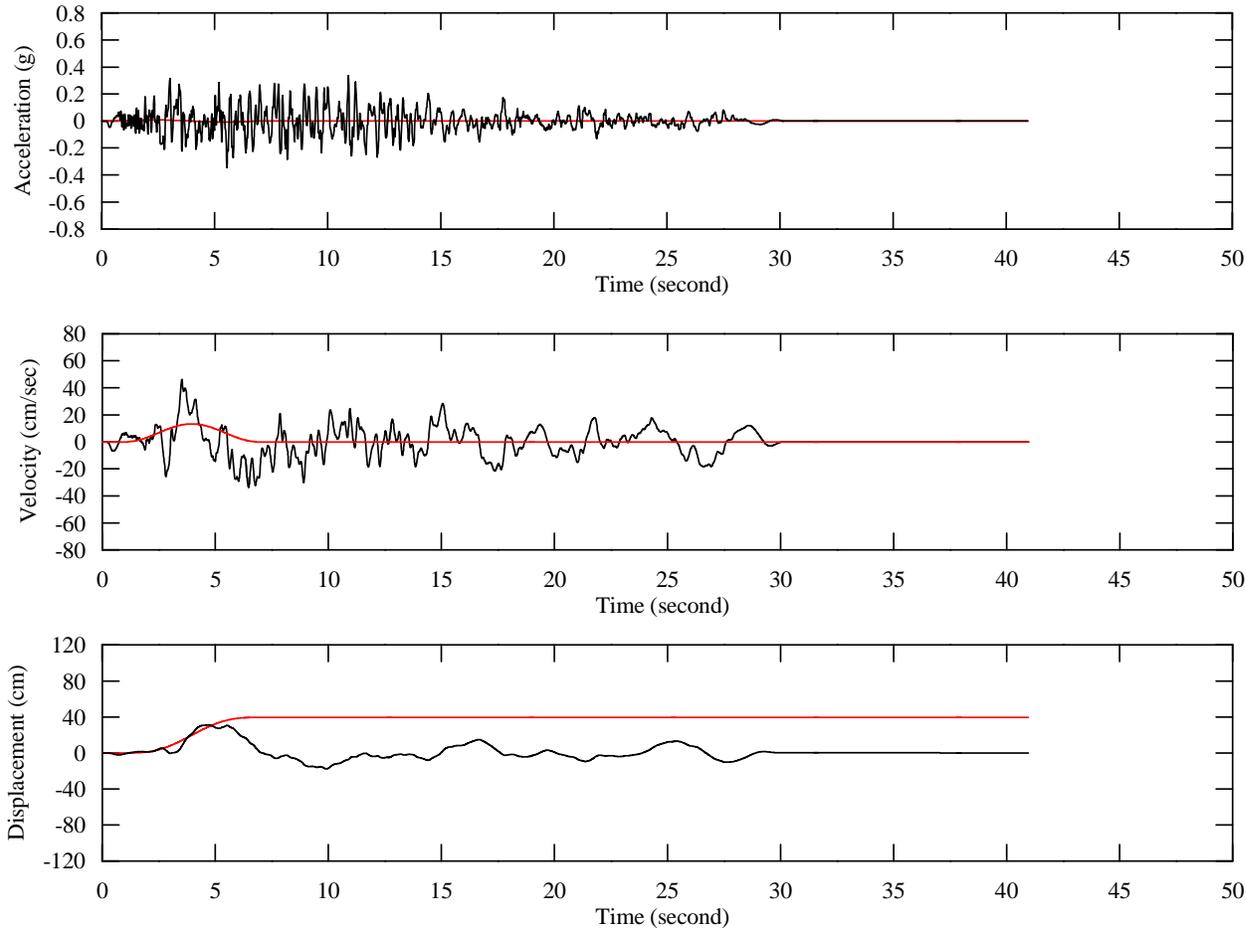


Figure 20: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1999 Kocaeli Earthquake

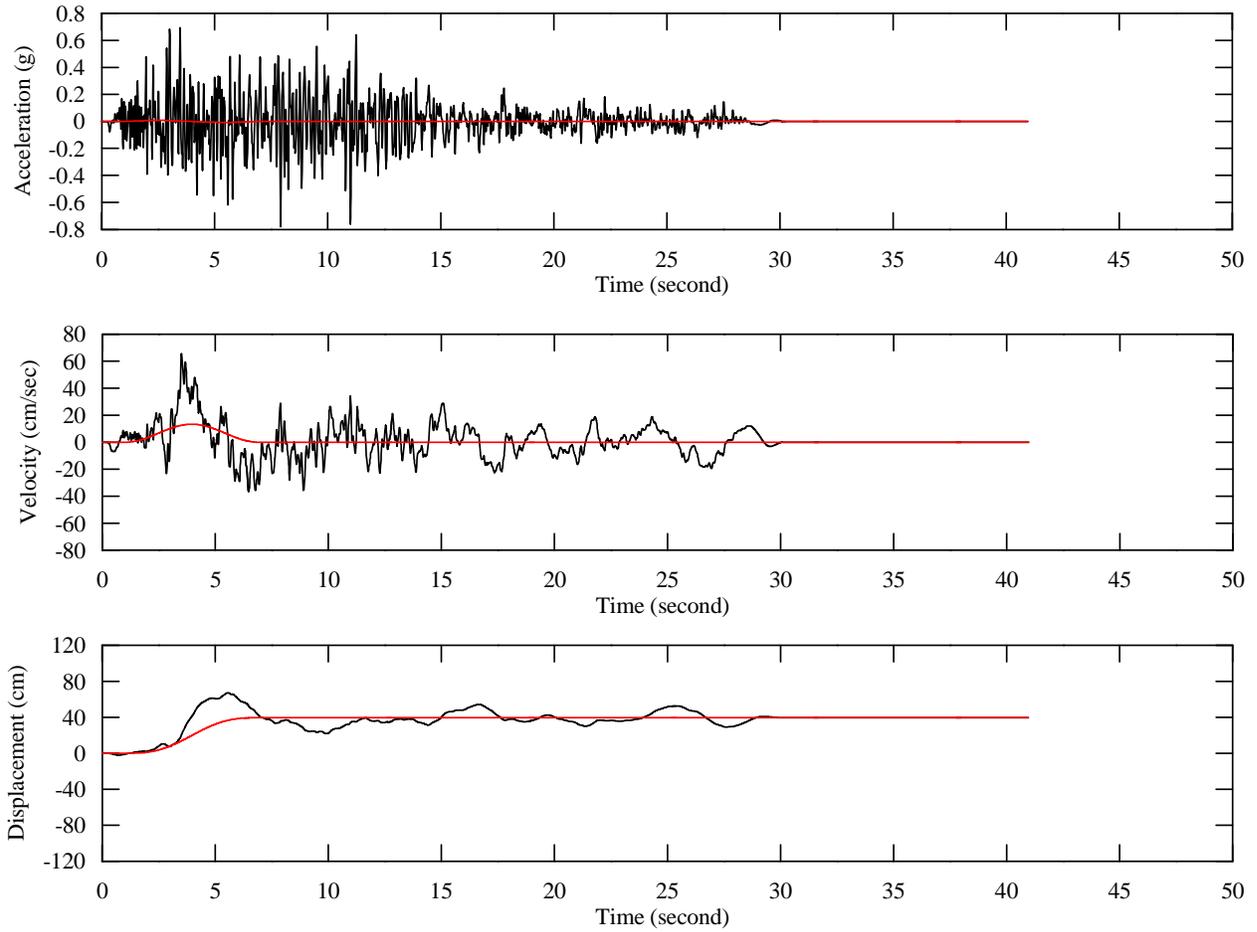


Figure 21: Fault parallel time histories including fling at ground surface, 1999 Kocaeli Earthquake

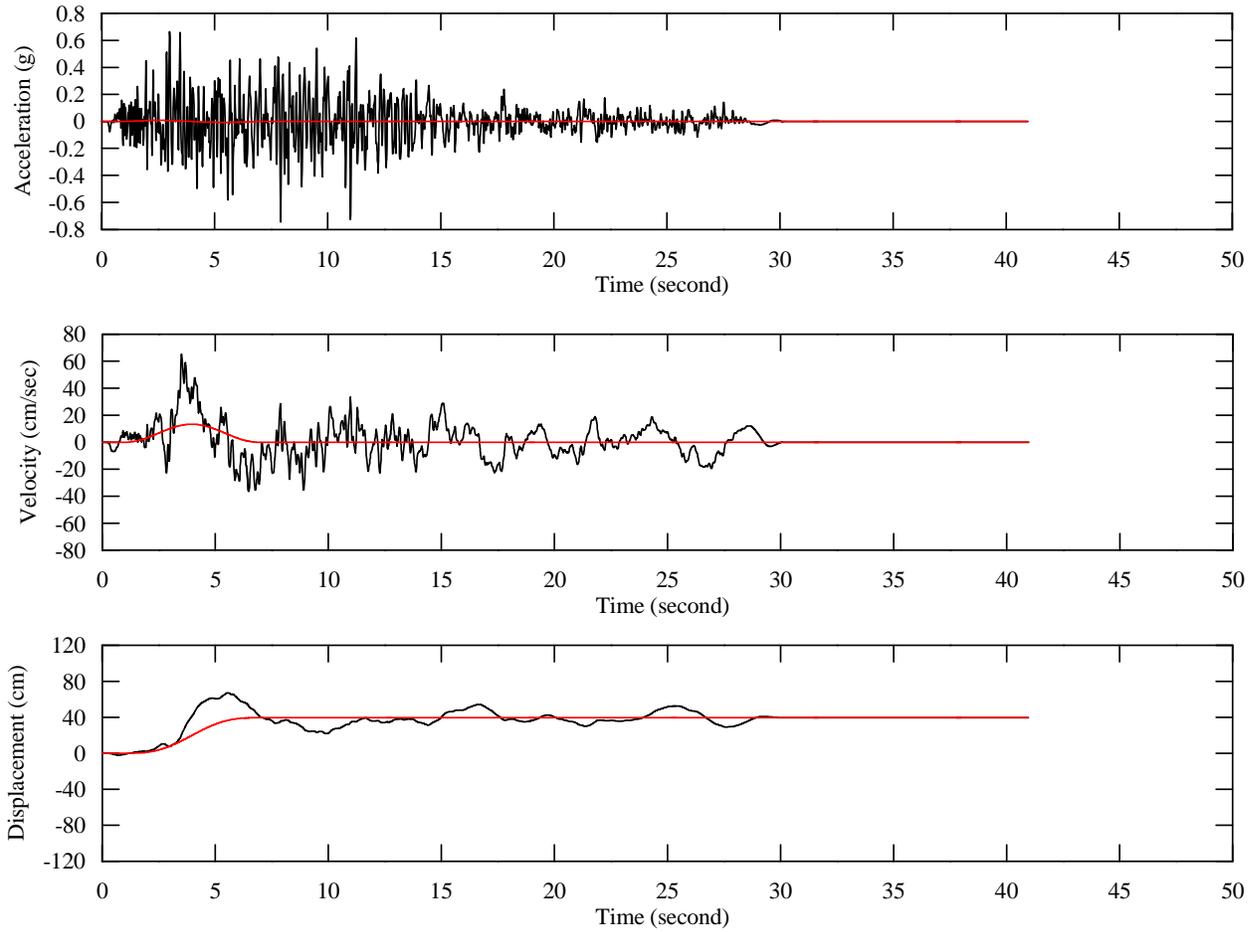


Figure 22: Fault parallel time histories including fling at crown of the tunnel, 1999 Kocaeli Earthquake

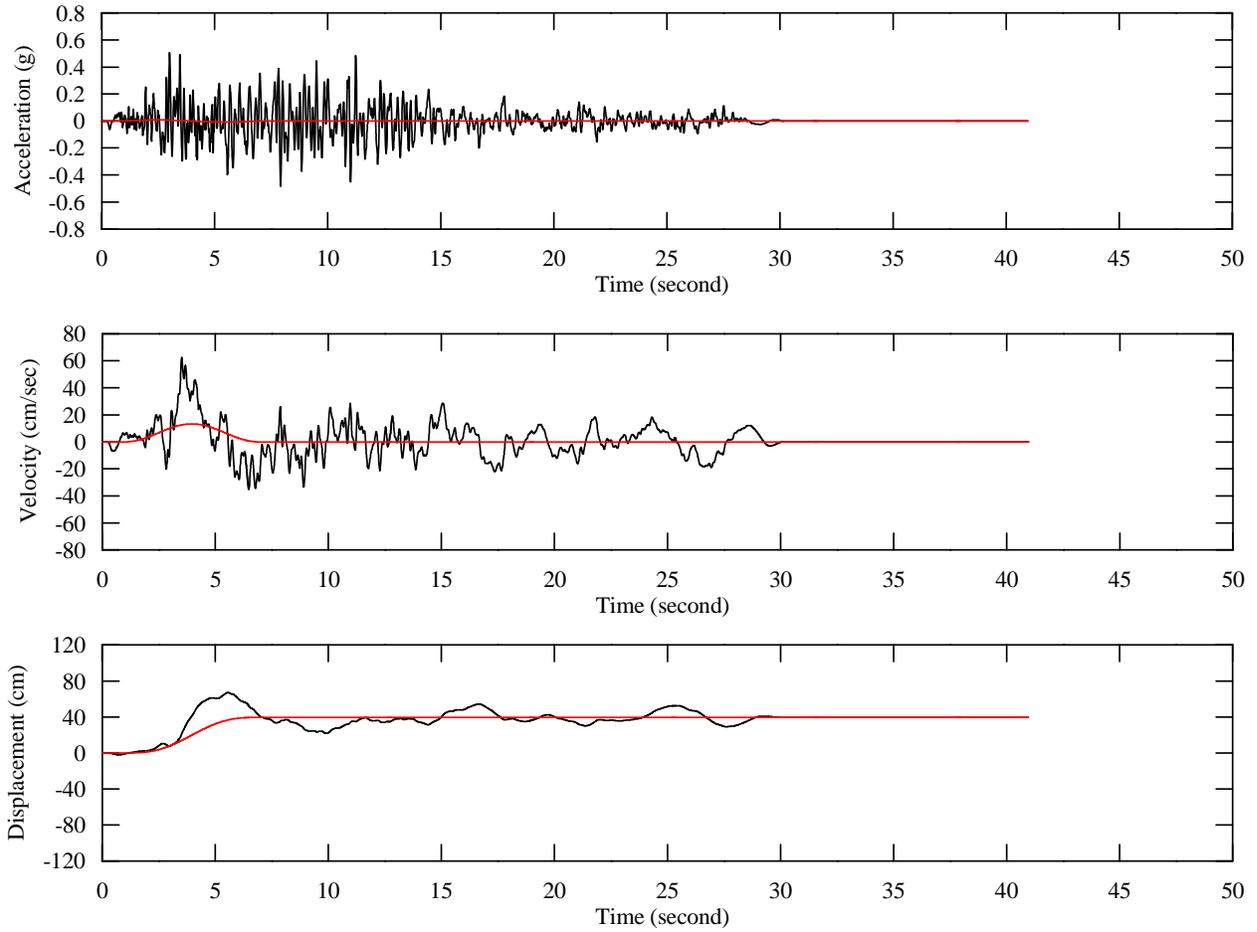


Figure 23: Fault parallel time histories including fling at top of side wall, 1999 Kocaeli Earthquake

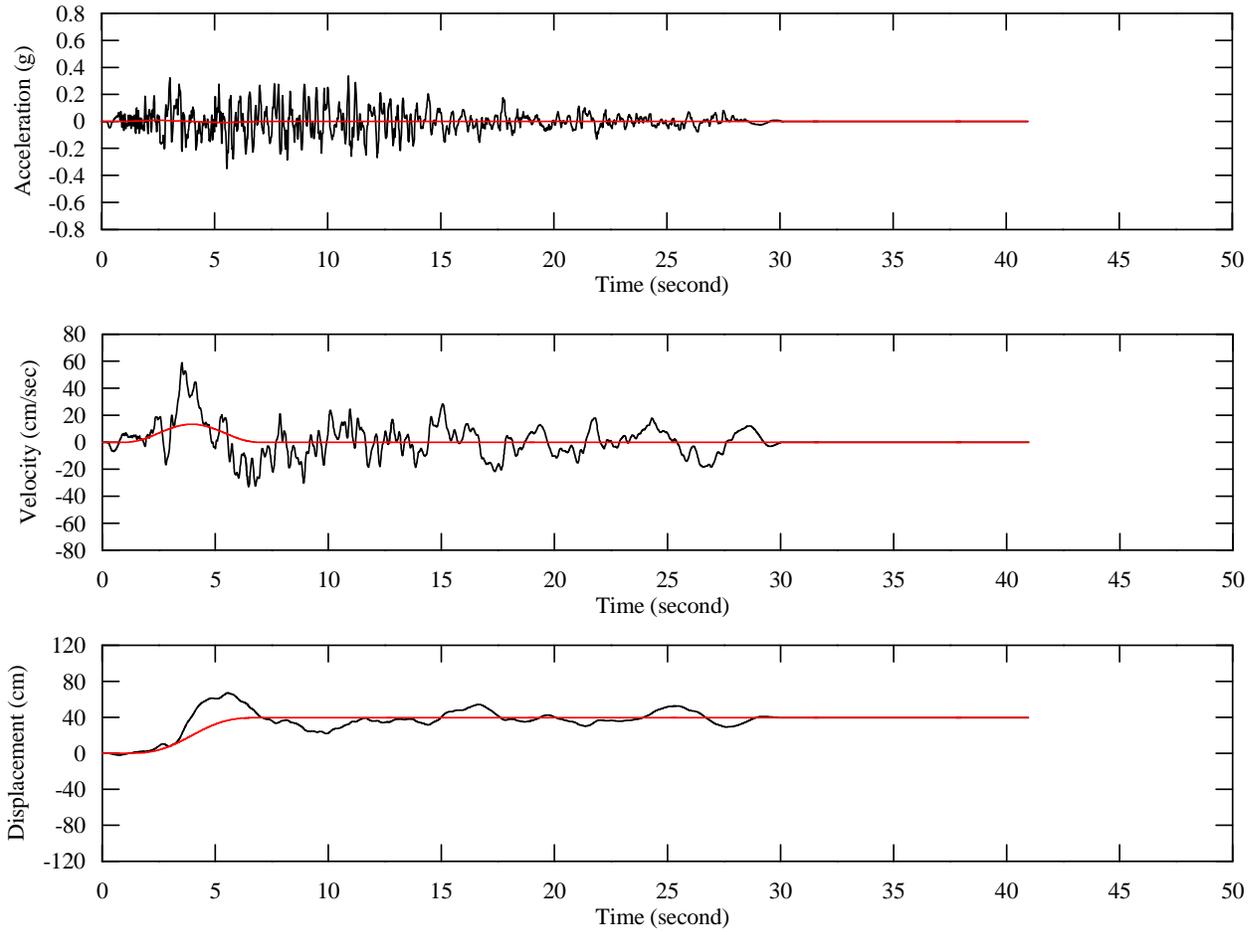


Figure 24: Fault parallel time histories including fling at invert of the tunnel, 1999 Kocaeli Earthquake

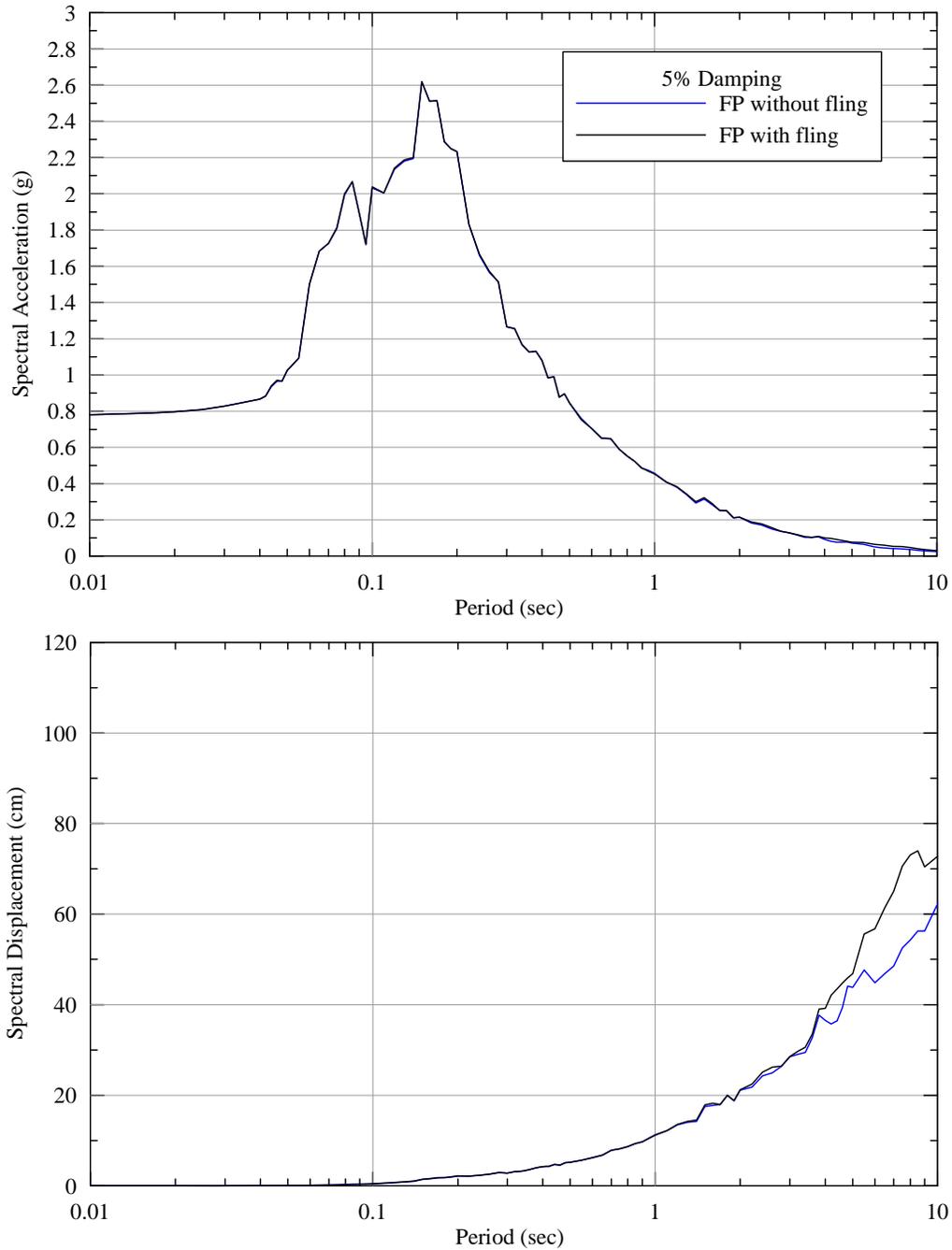


Figure 25: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1999 Kocaeli Earthquake

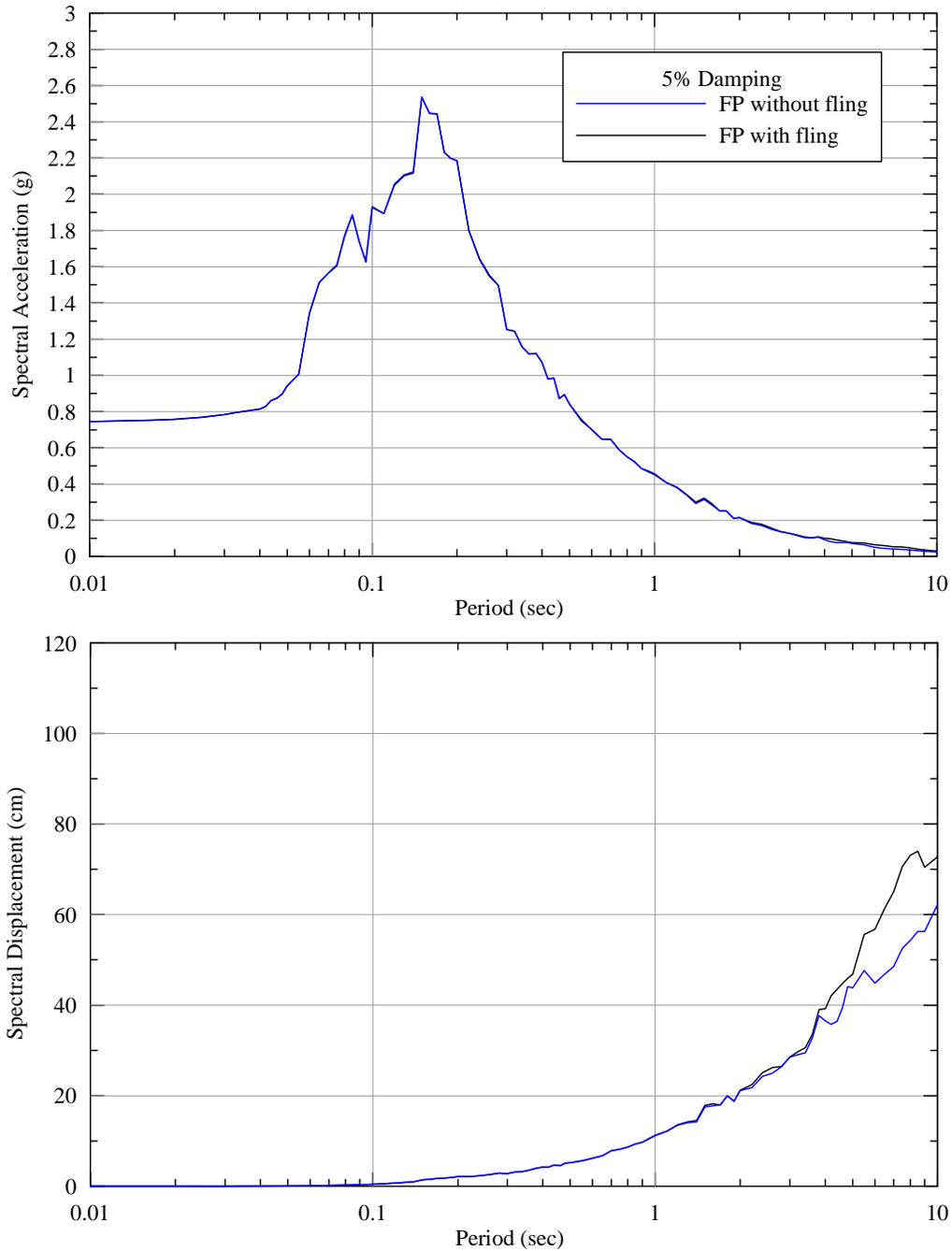


Figure 26: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1999 Kocaeli Earthquake

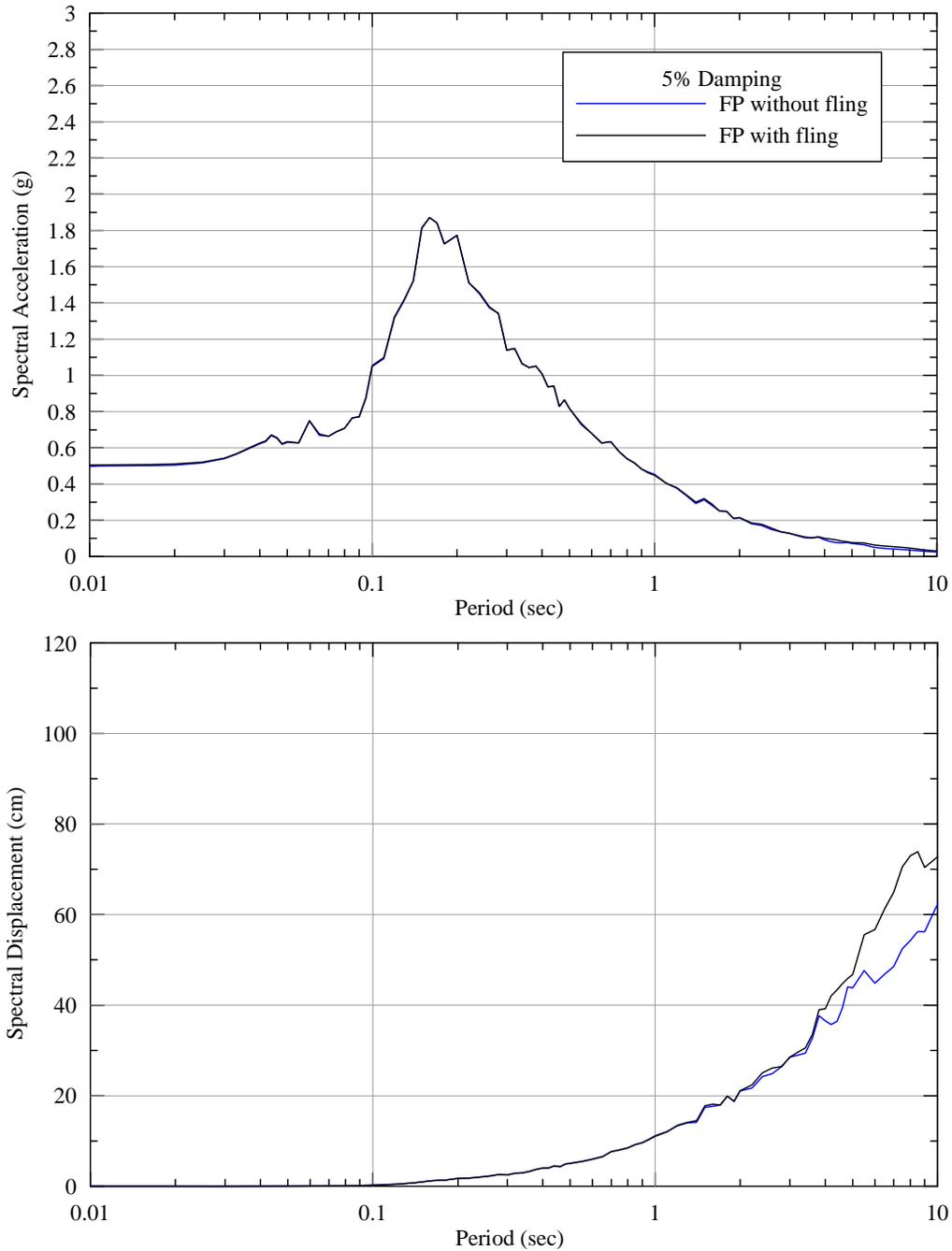


Figure 27: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1999 Kocaeli Earthquake

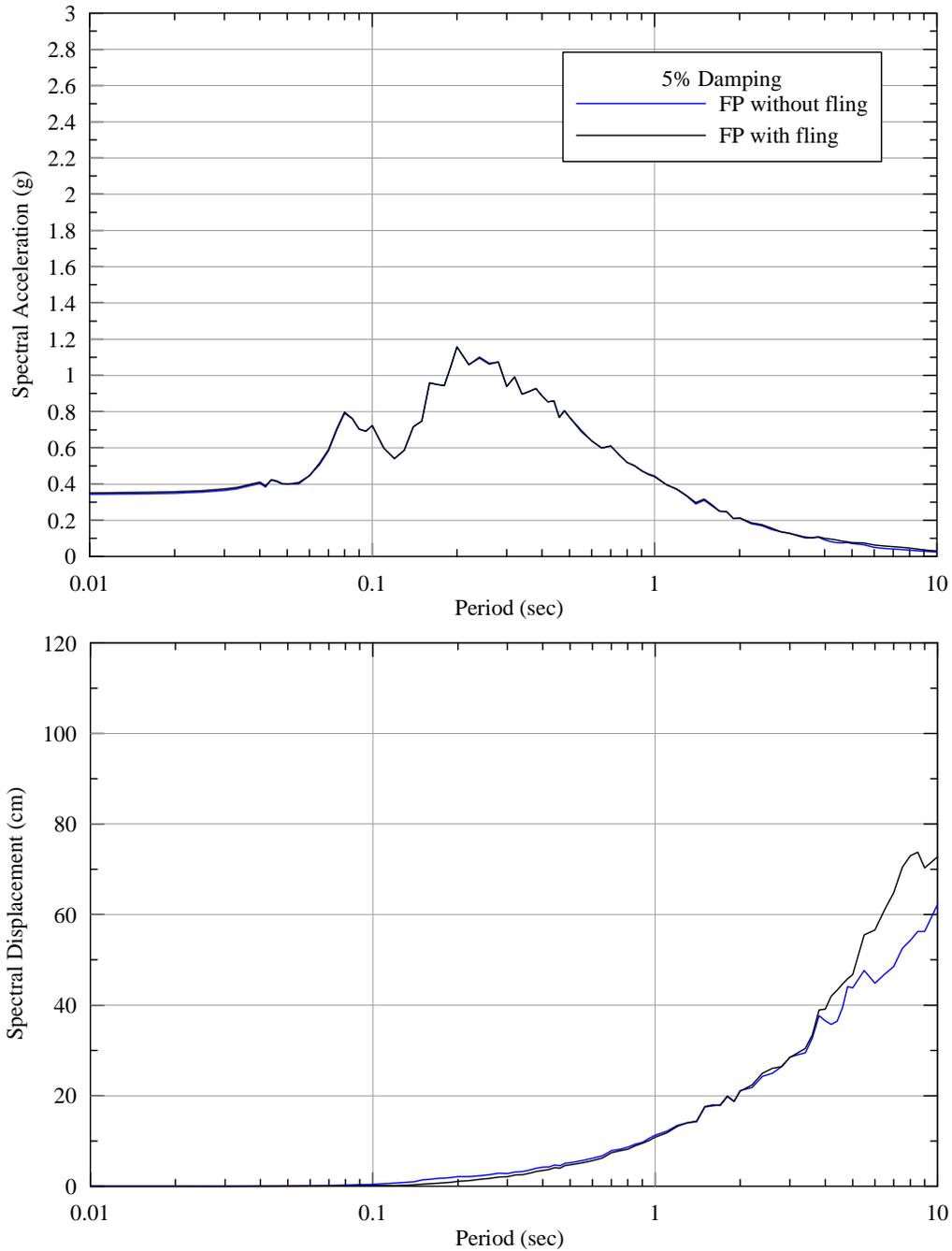


Figure 28: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1999 Kocaeli Earthquake

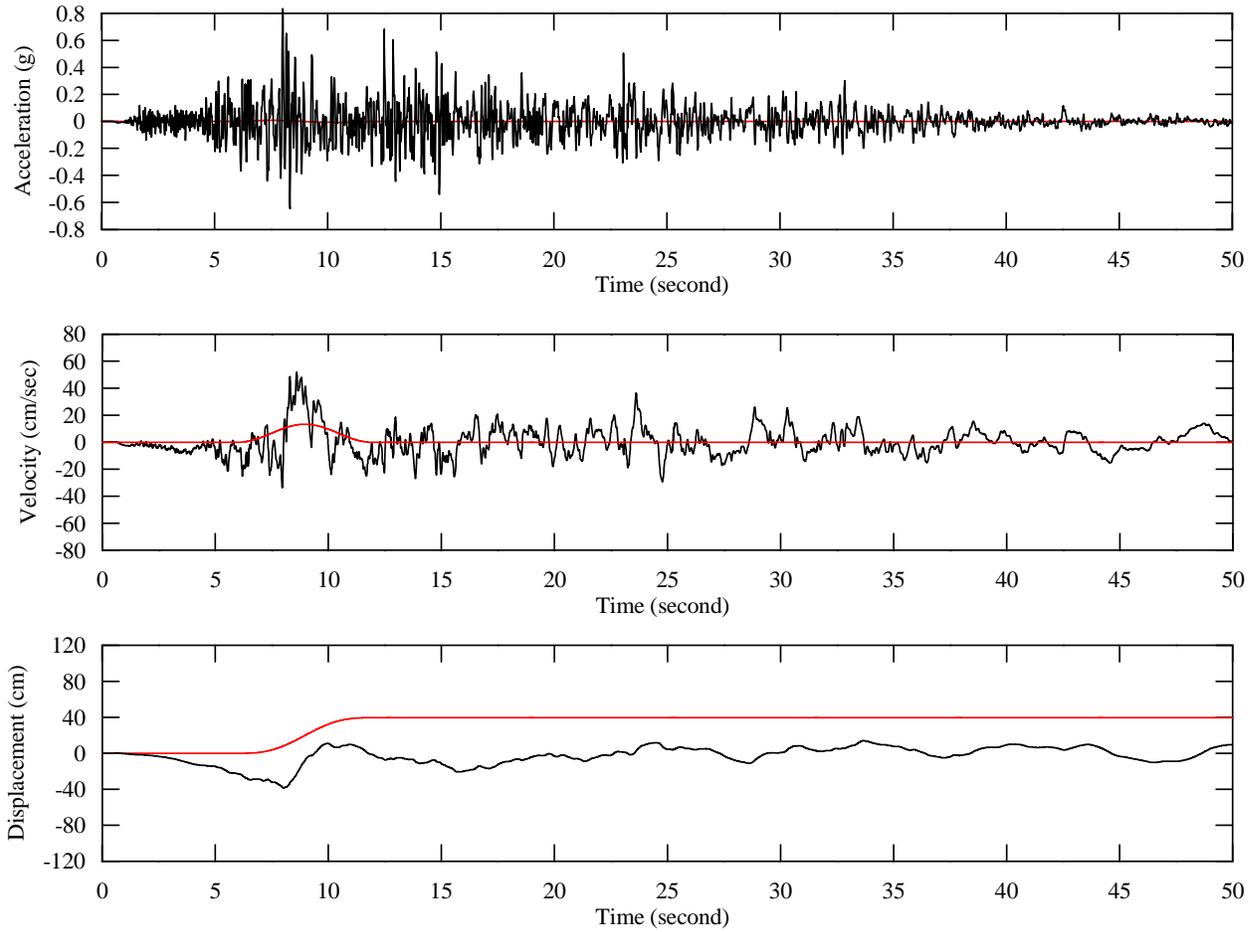


Figure 29: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

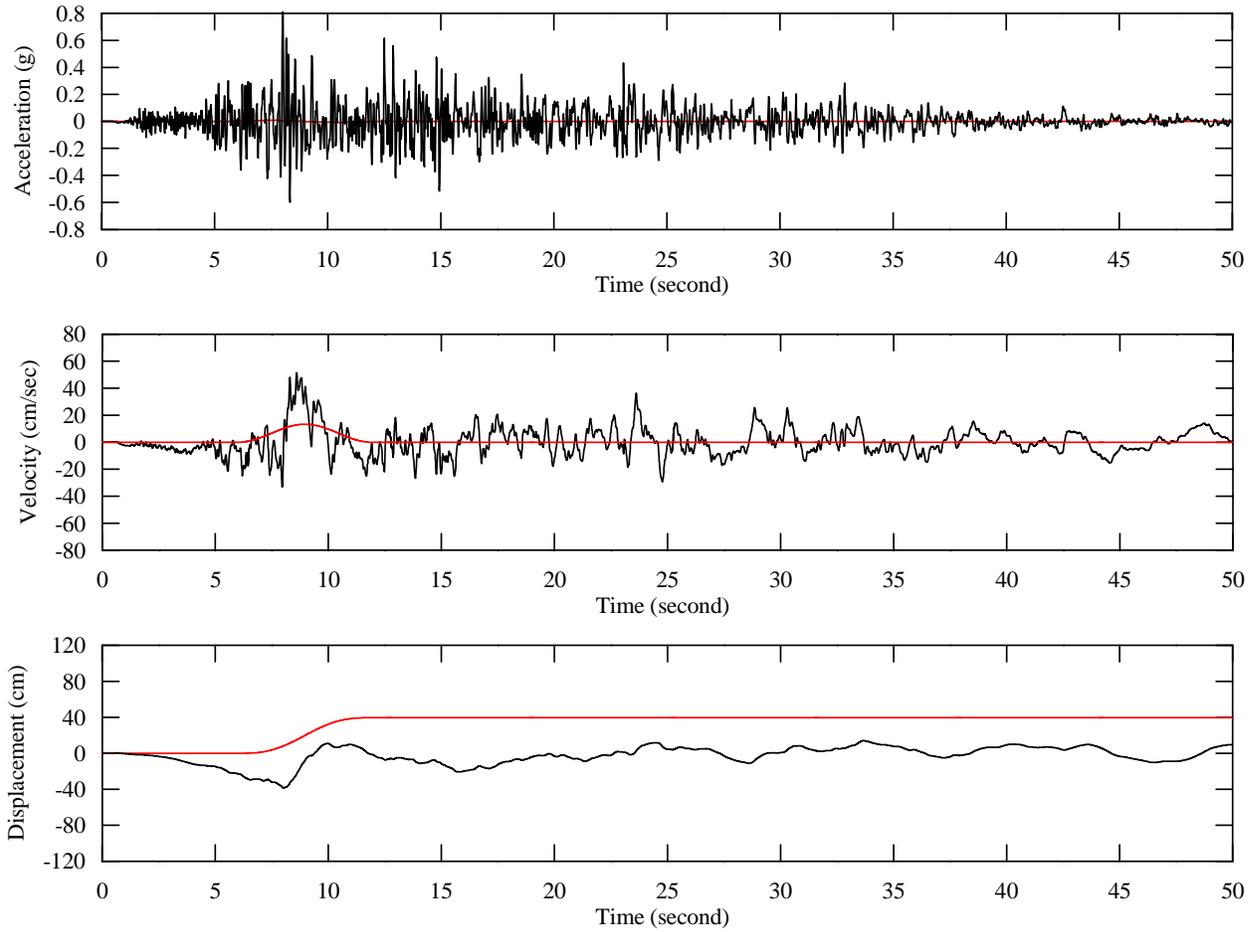


Figure 30: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

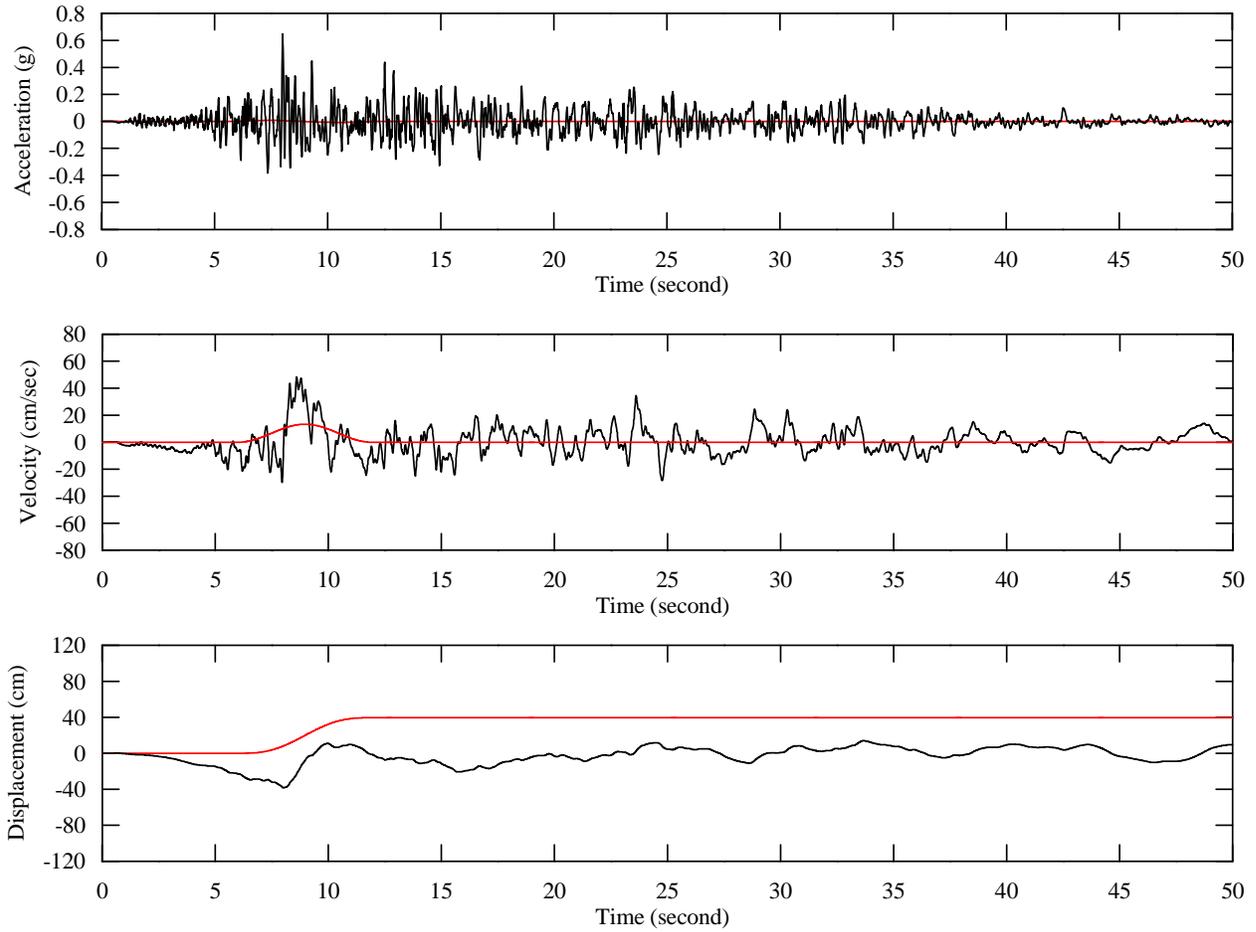


Figure 31: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

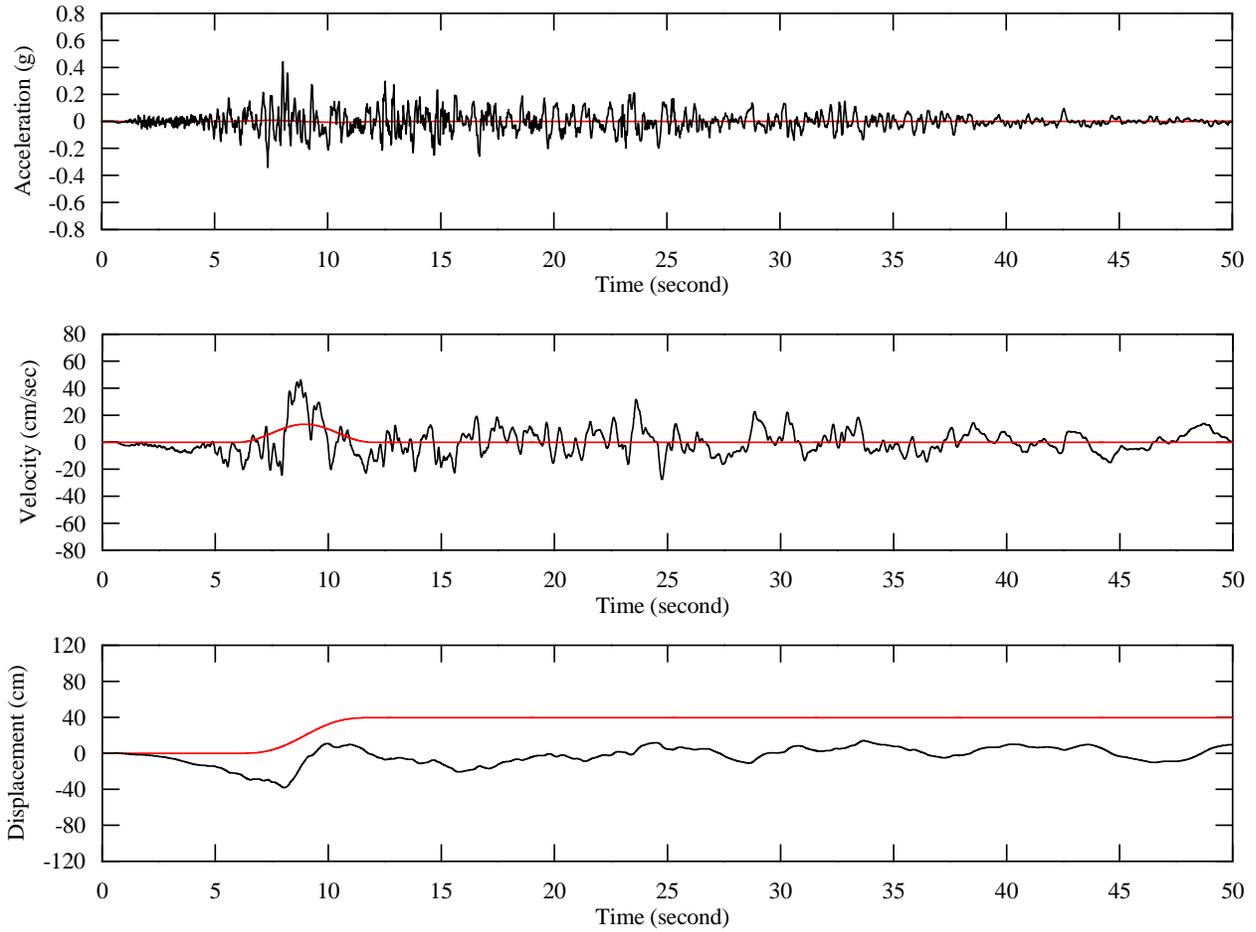


Figure 32: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

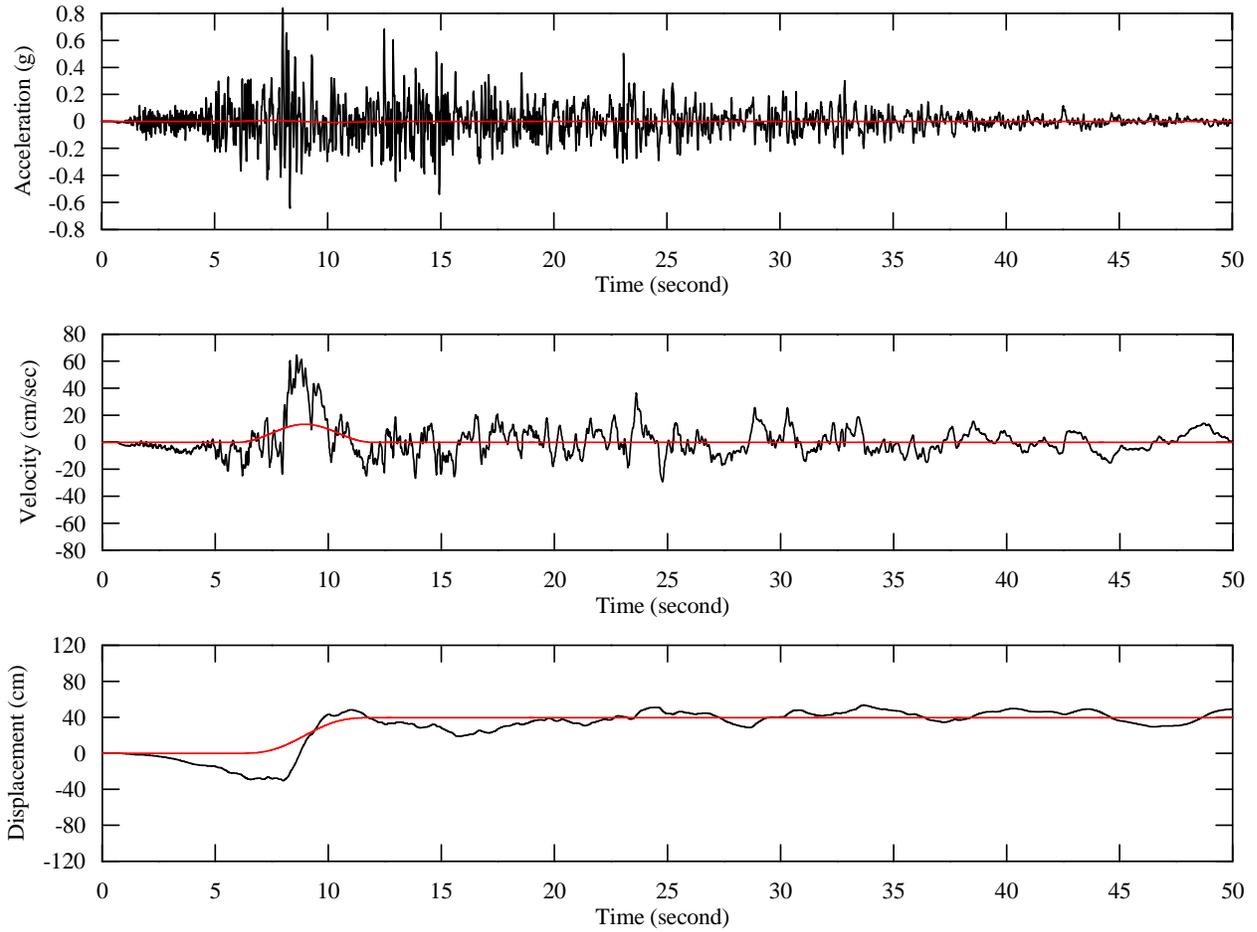


Figure 33: Fault parallel time histories including fling at ground surface, 1999 Chi-Chi Earthquake

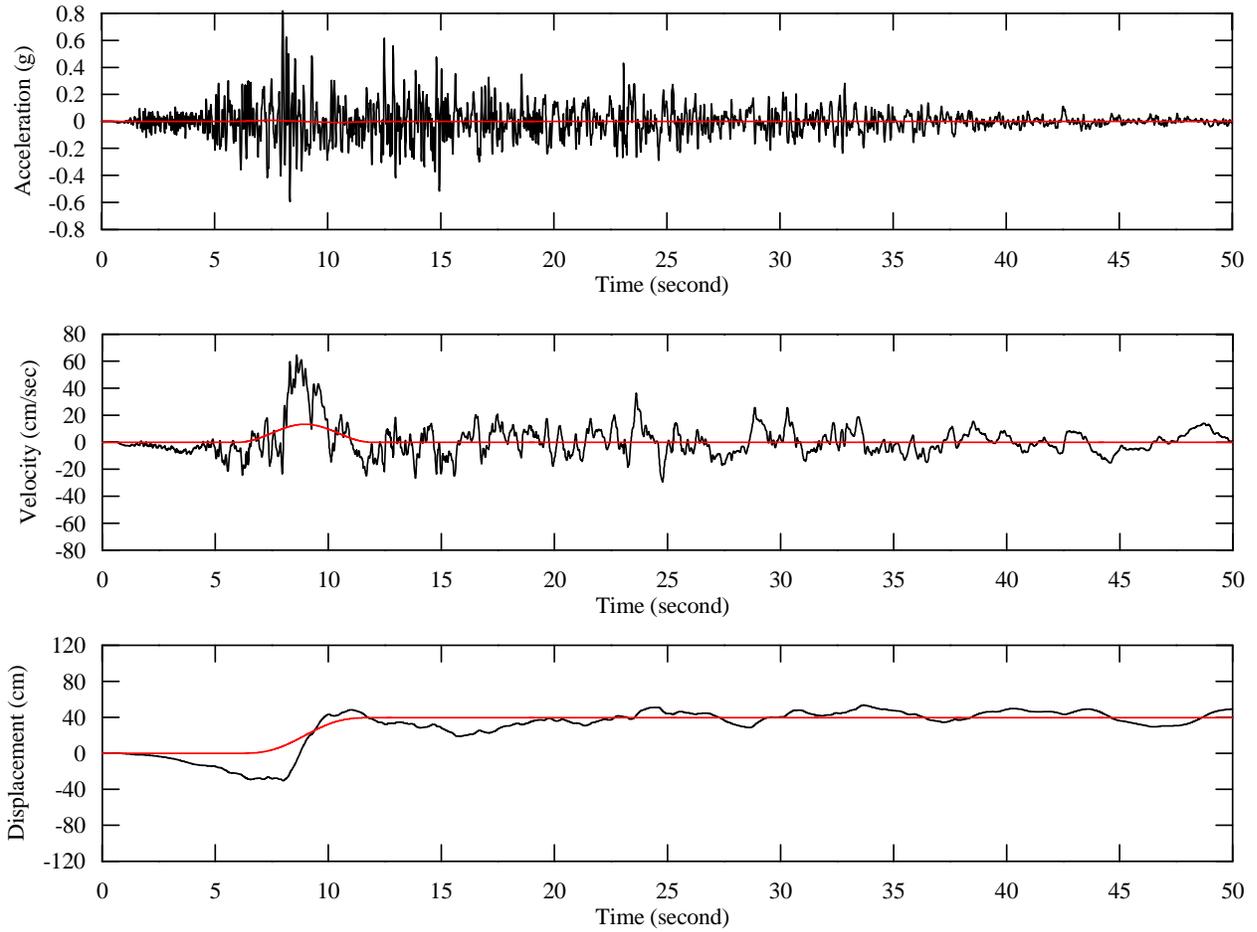


Figure 34: Fault parallel time histories including fling at crown of the tunnel, 1999 Chi-Chi Earthquake

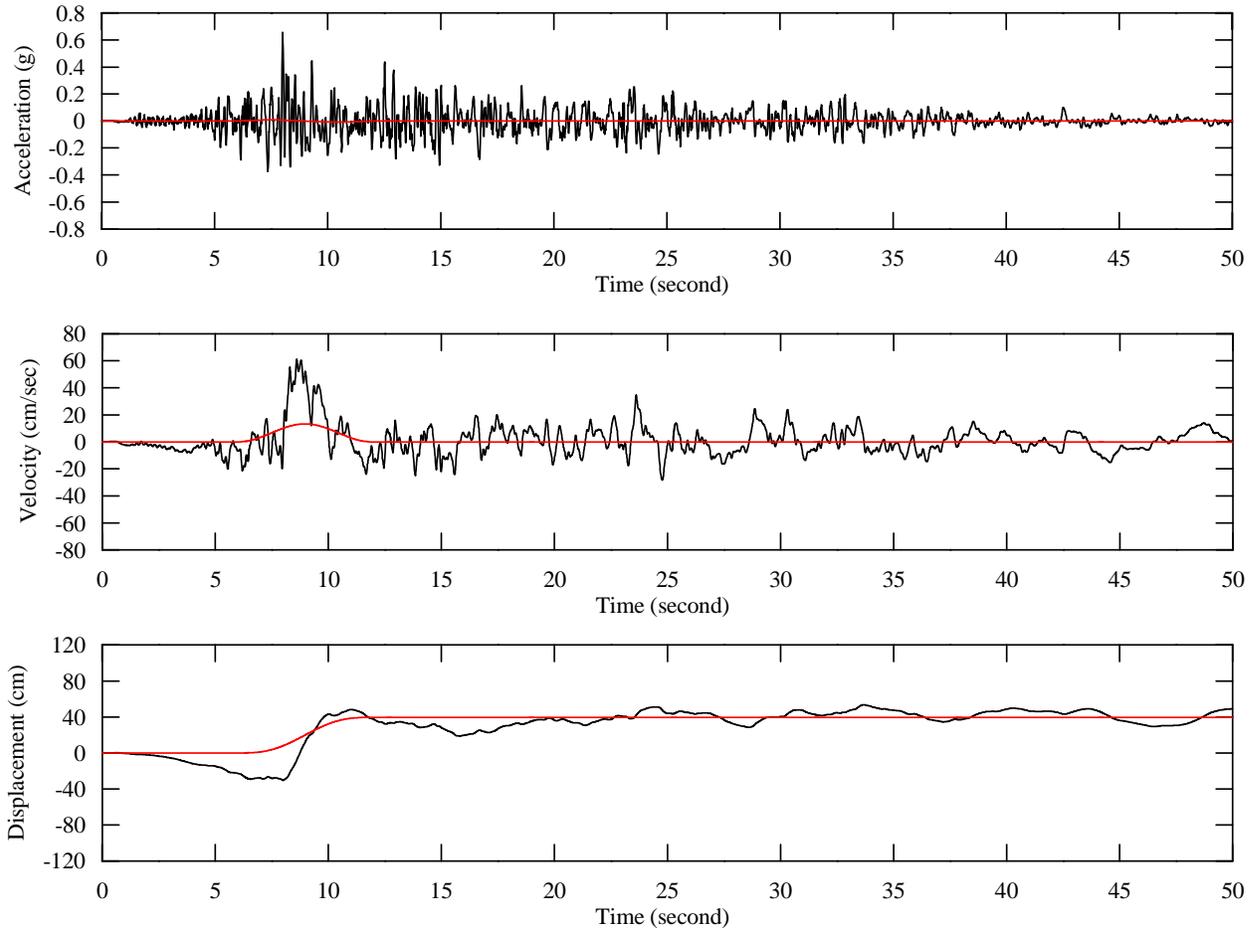


Figure 35: Fault parallel time histories including fling at top of side wall, 1999 Chi-Chi Earthquake

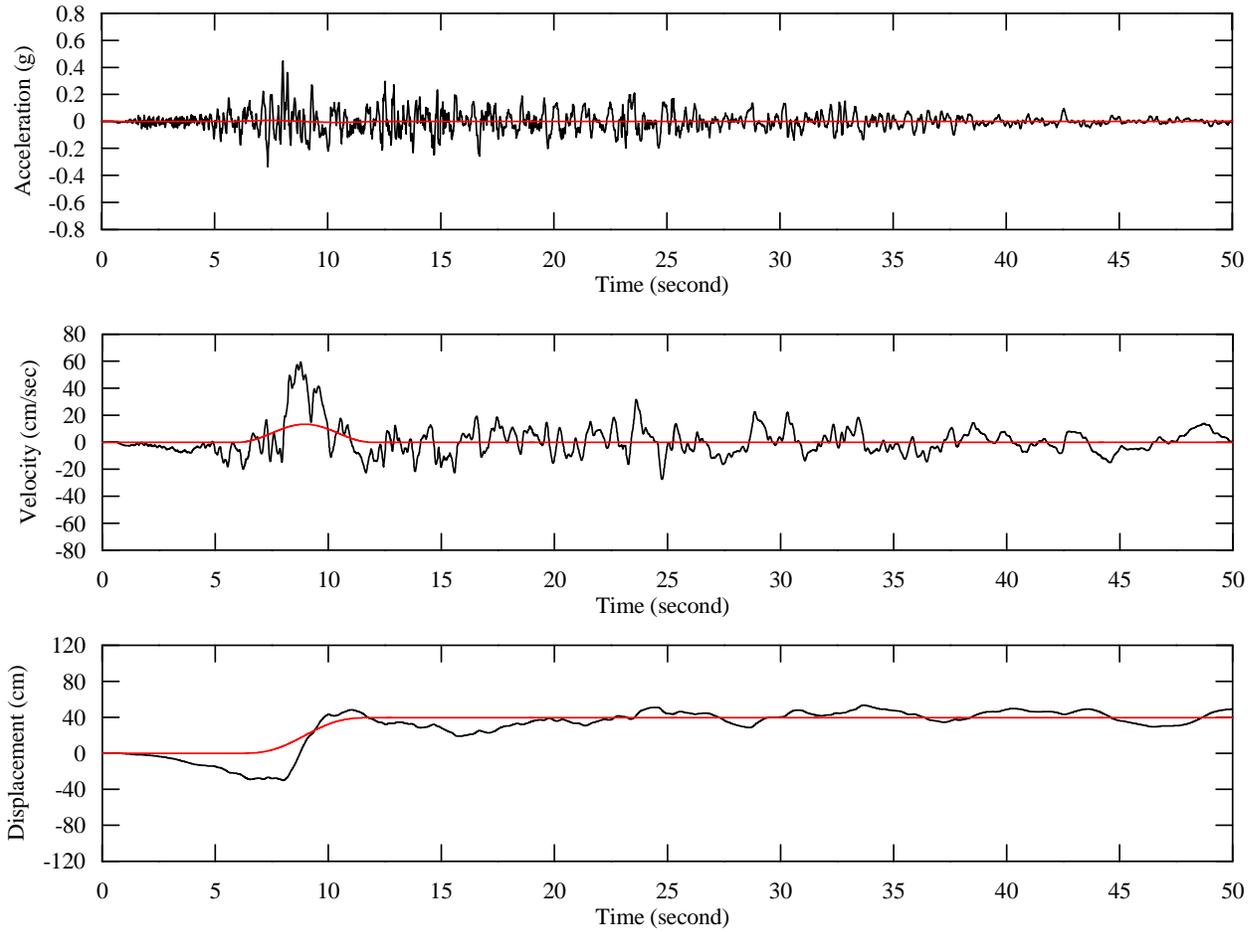


Figure 36: Fault parallel time histories including fling at invert of the tunnel, 1999 Chi-Chi Earthquake

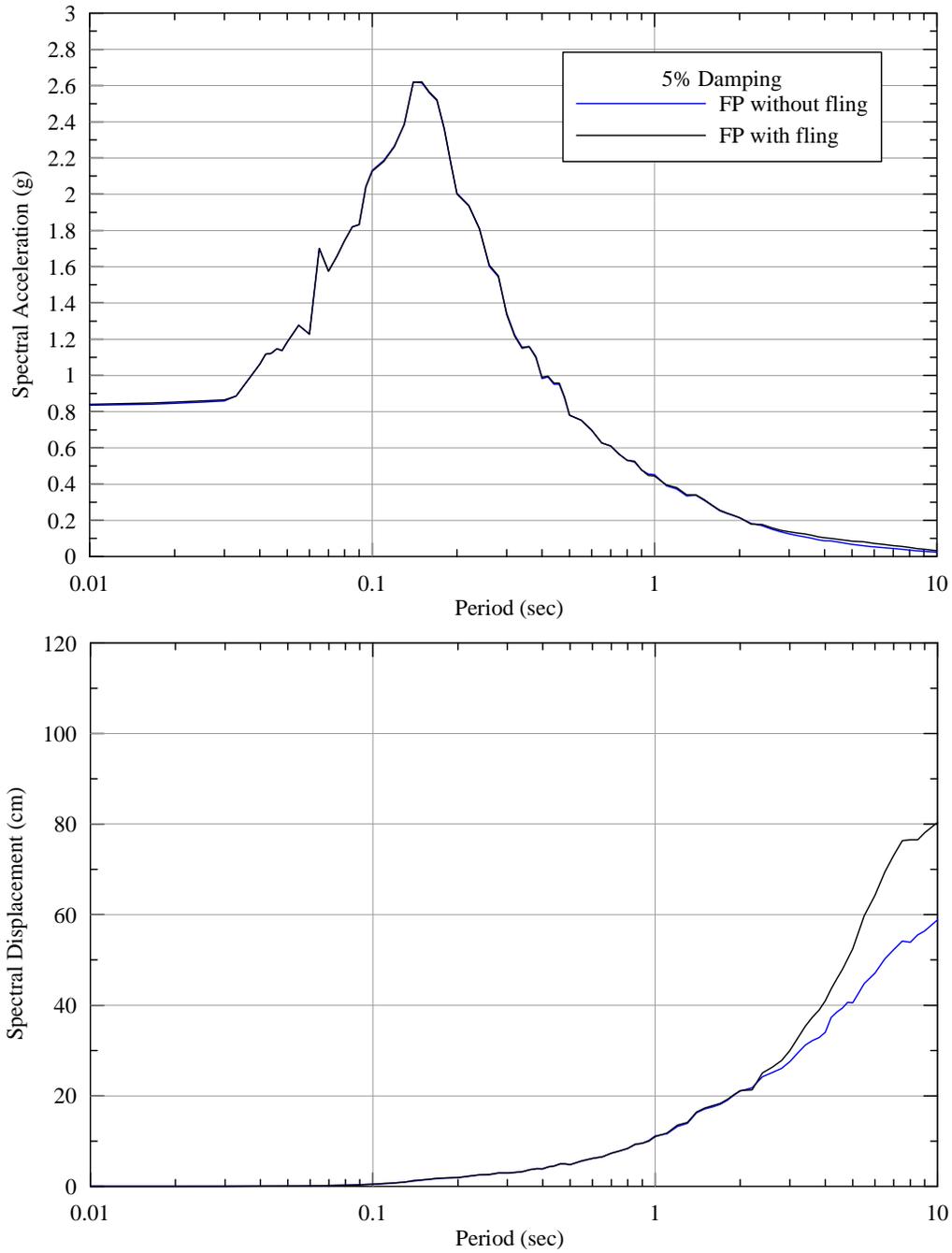


Figure 37: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1999 Chi-Chi Earthquake

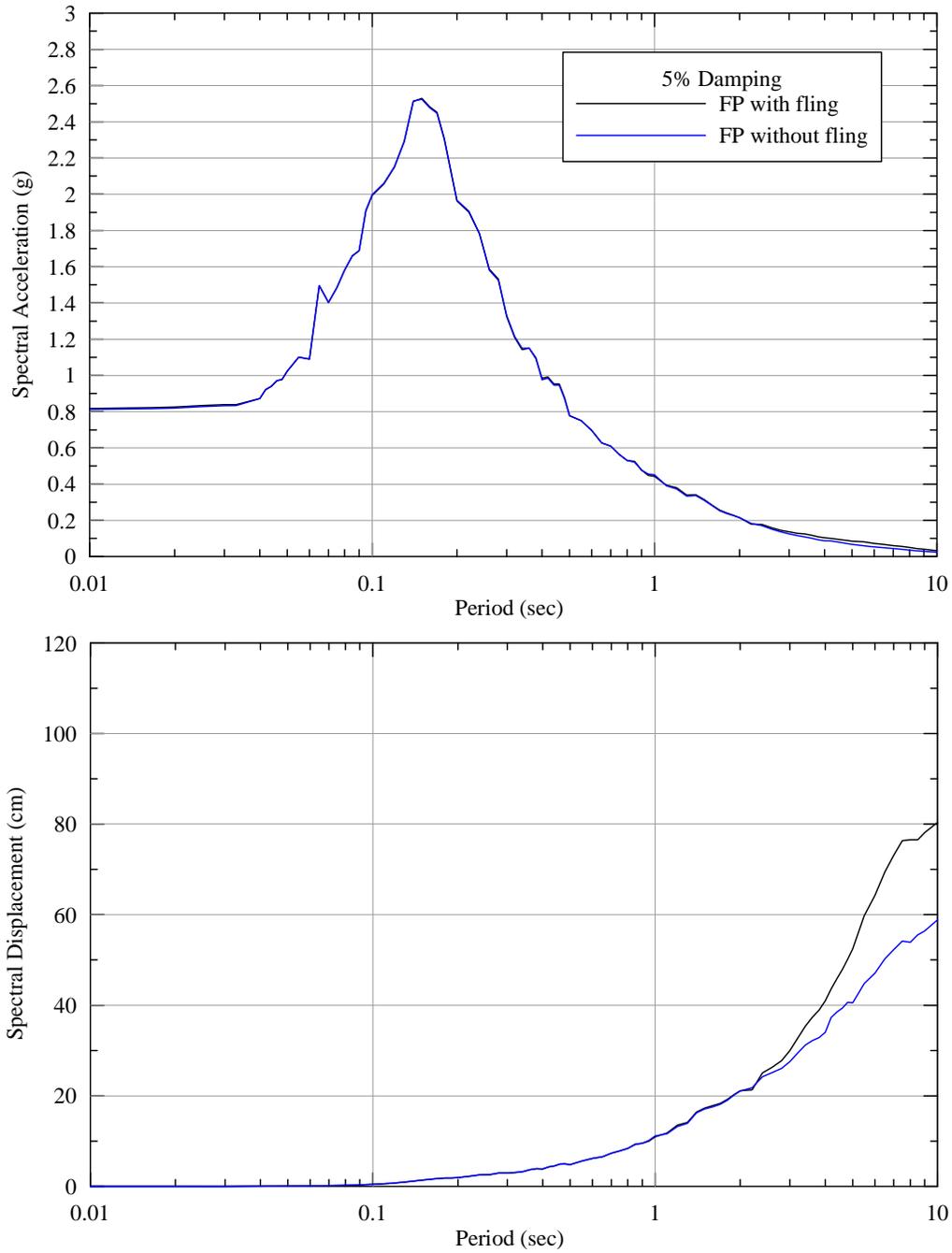


Figure 38: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1999 Chi-Chi Earthquake

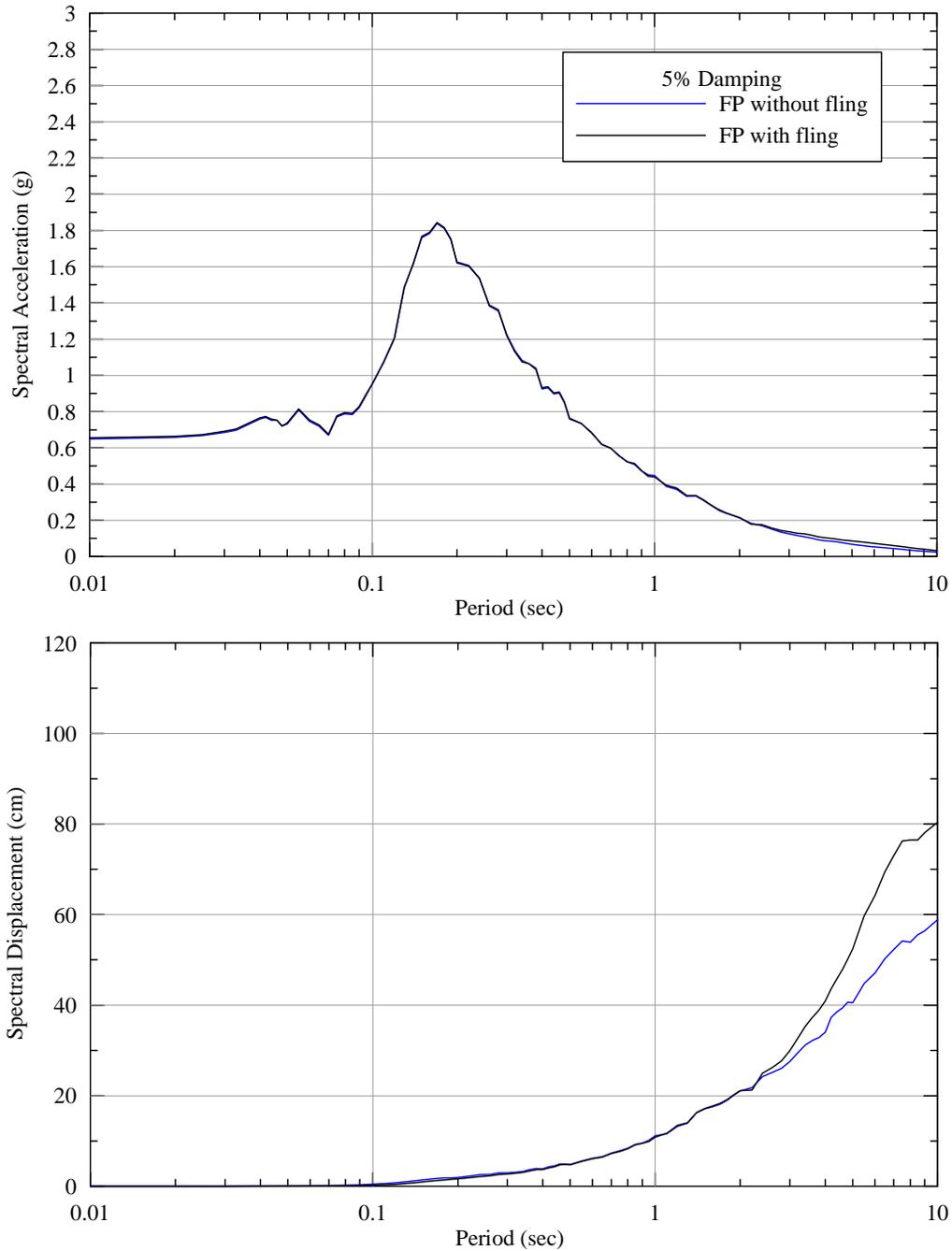


Figure 39: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1999 Chi-Chi Earthquake

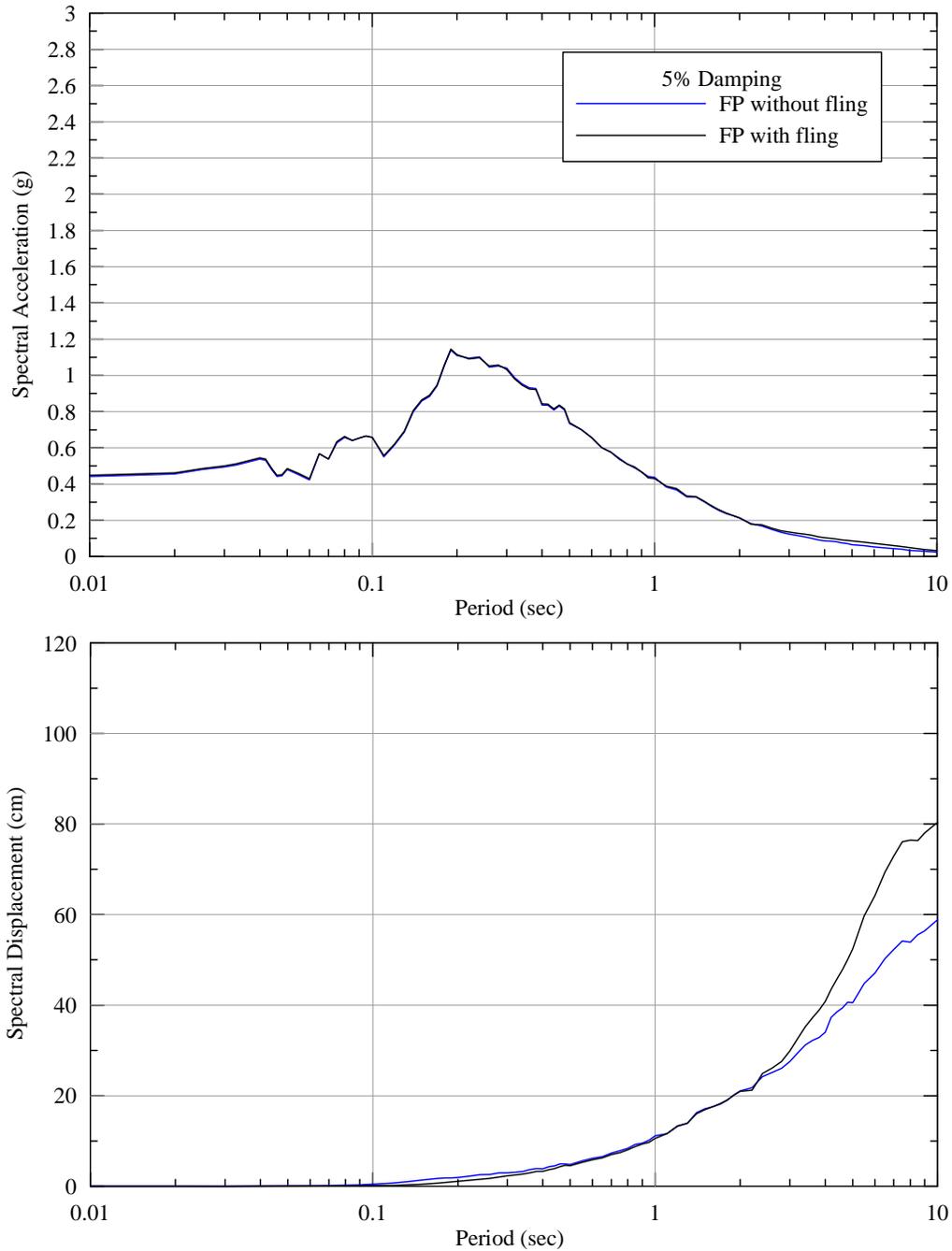


Figure 40: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1999 Chi-Chi Earthquake

WEST BATTERY TUNNEL (SHALLOW) PROFILE

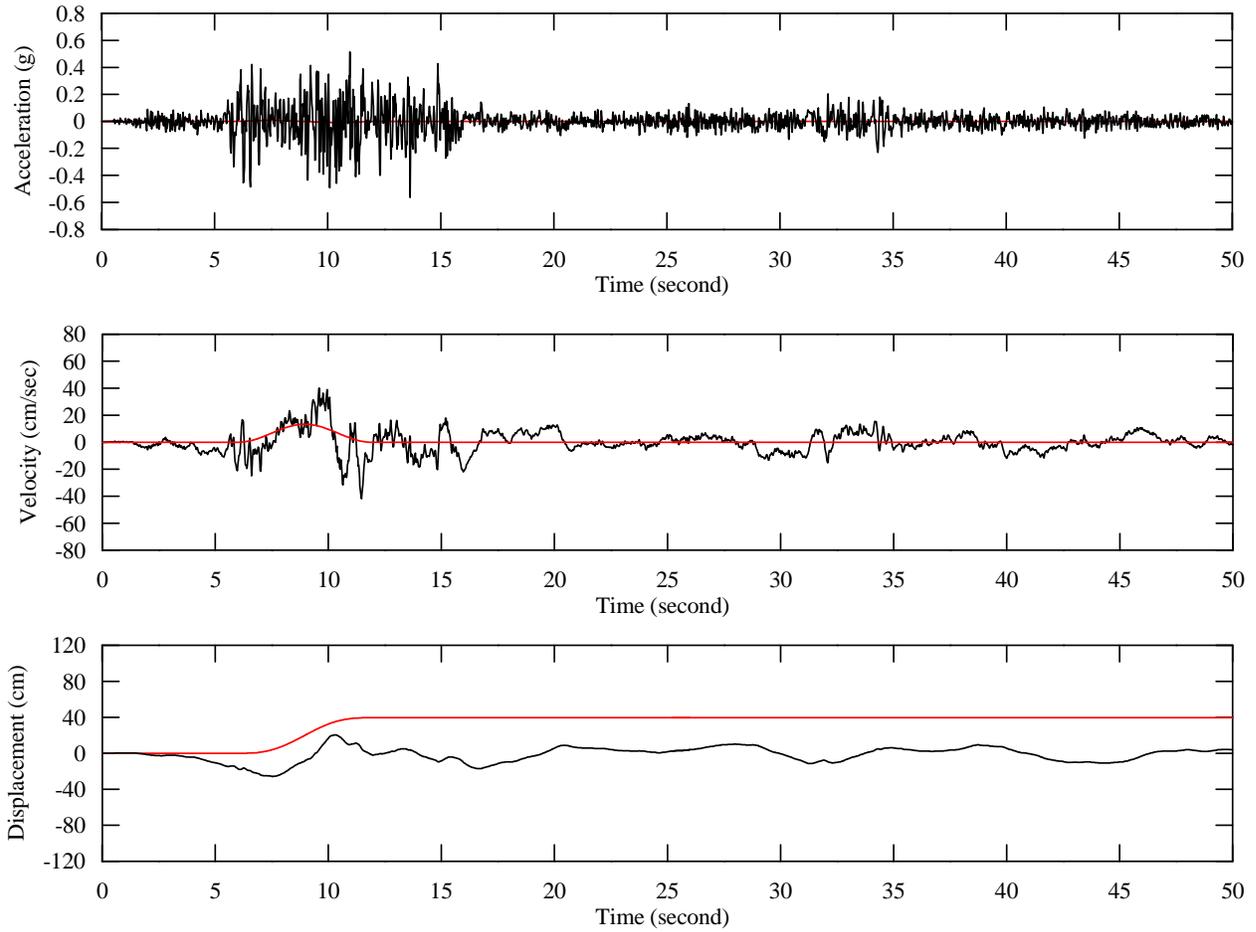


Figure 41: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1990 Manjil Earthquake

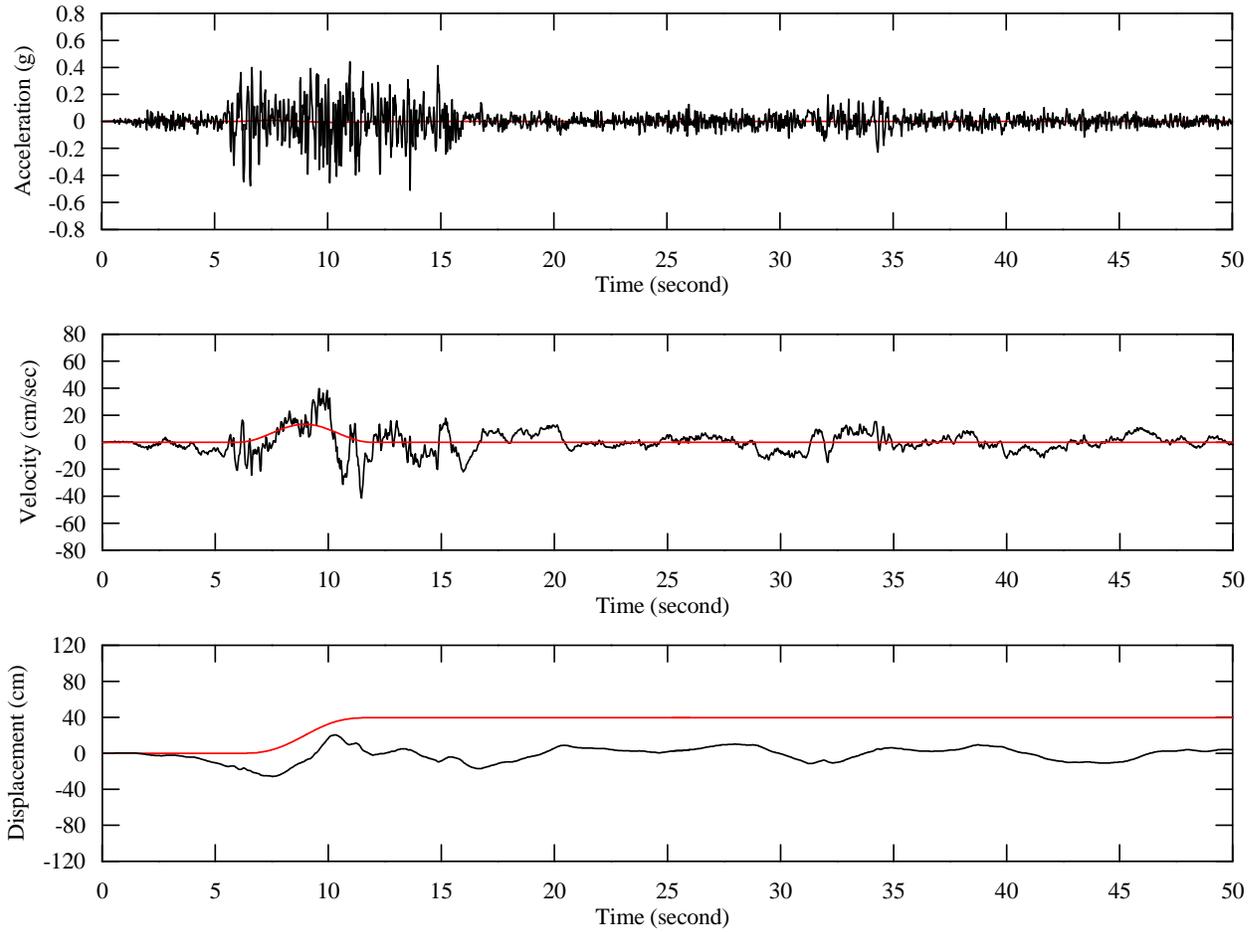


Figure 42: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1990 Manjil Earthquake

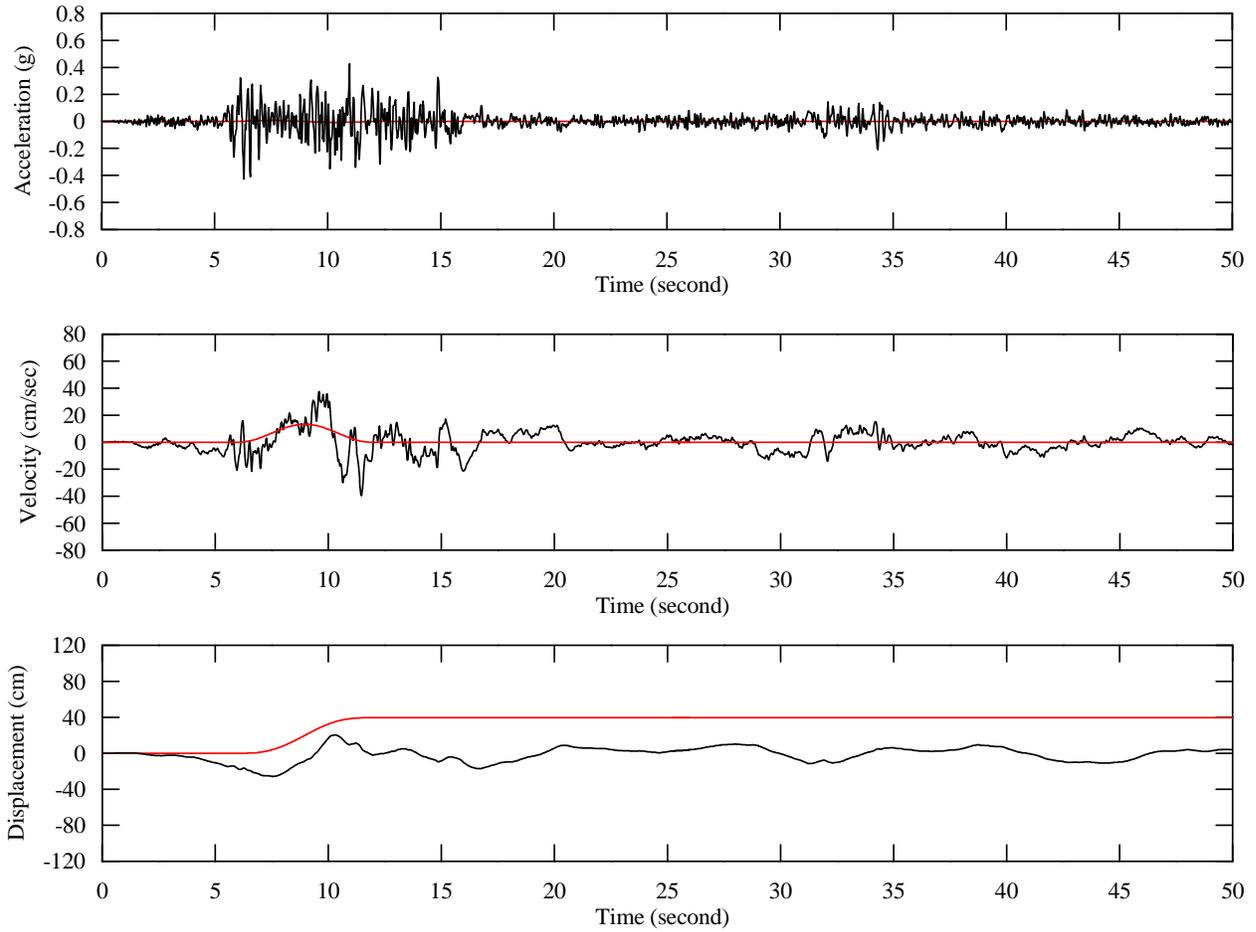


Figure 43: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1990 Manjil Earthquake

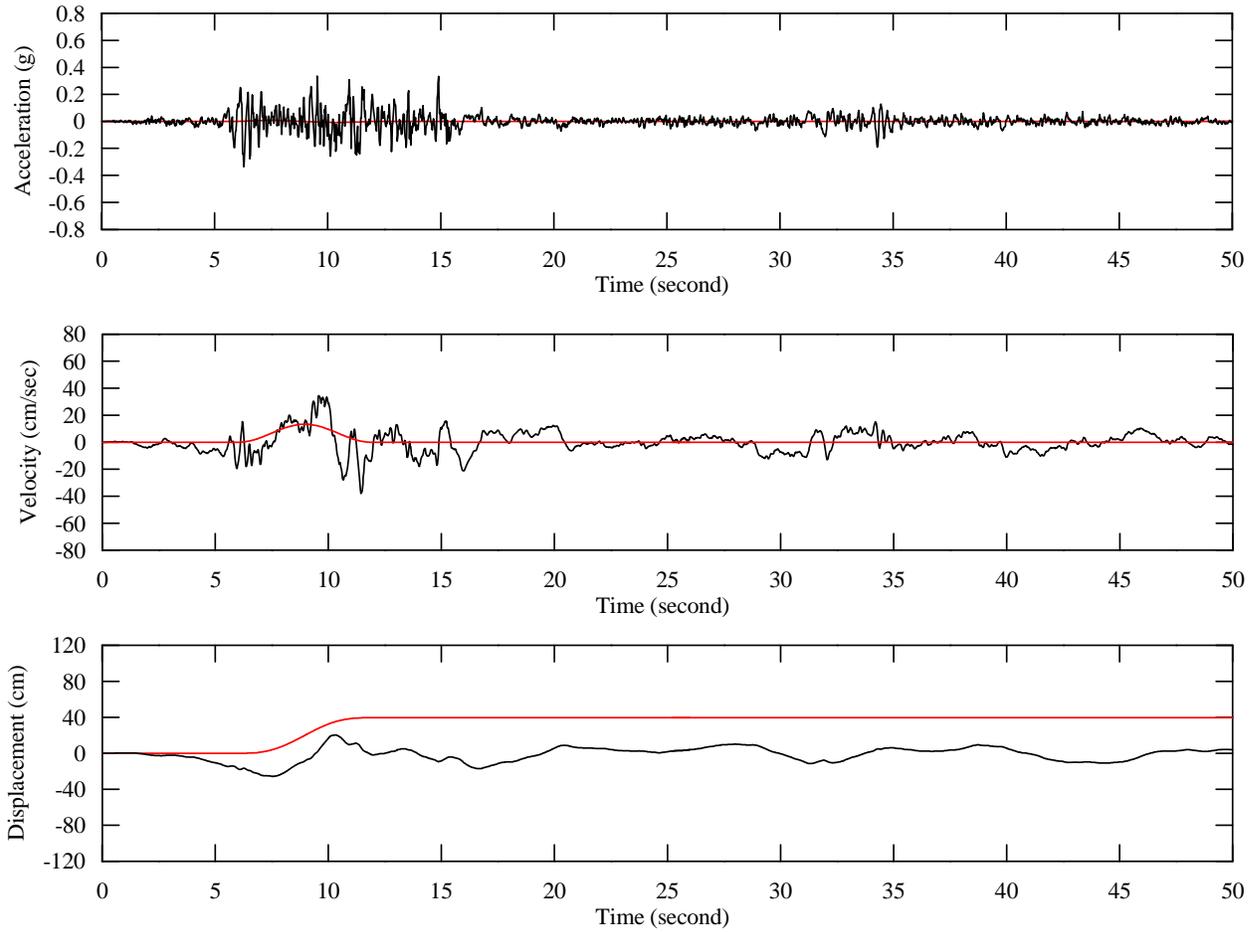


Figure 44: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1990 Manjil Earthquake

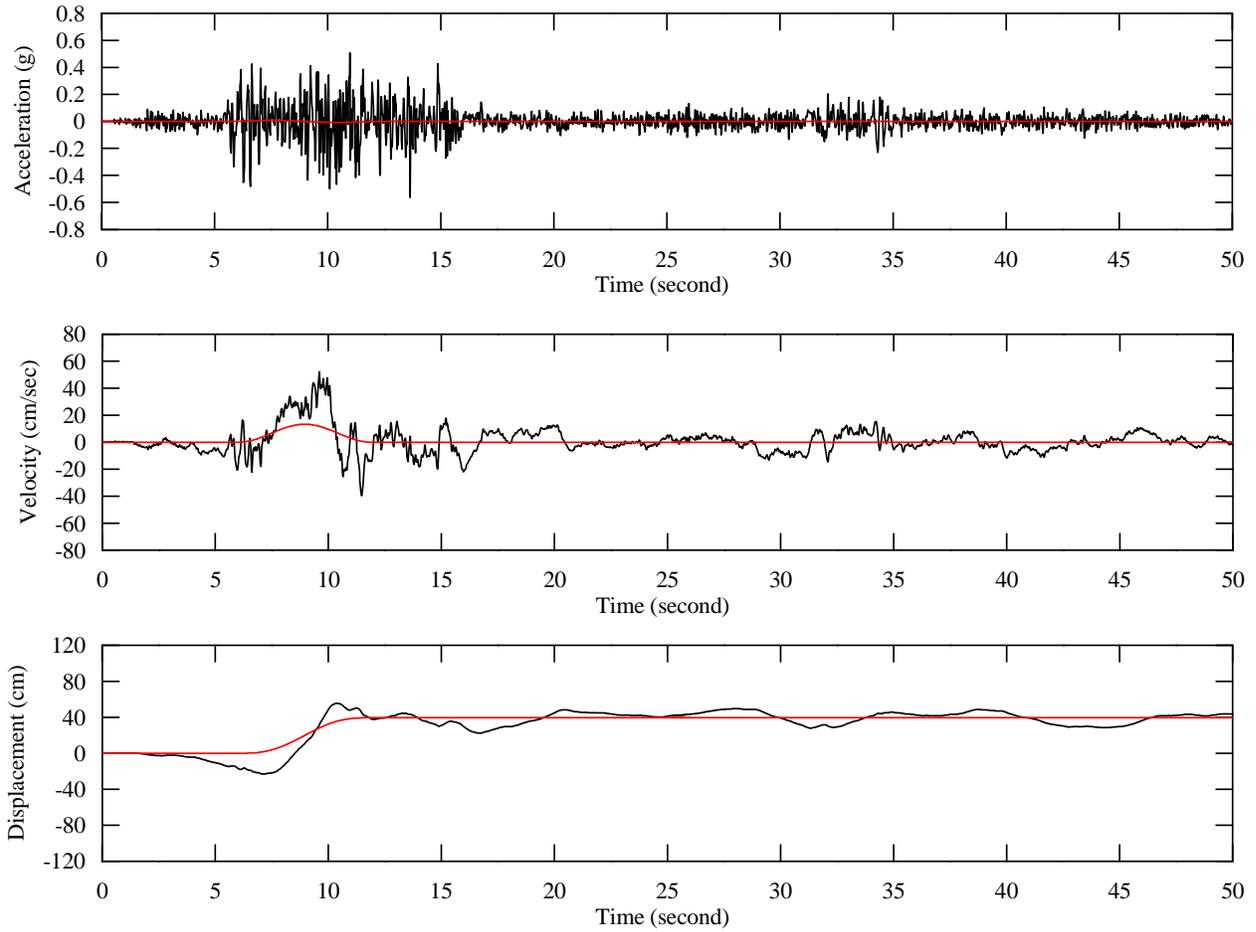


Figure 45: Fault parallel time histories including fling at ground surface, 1990 Manjil Earthquake

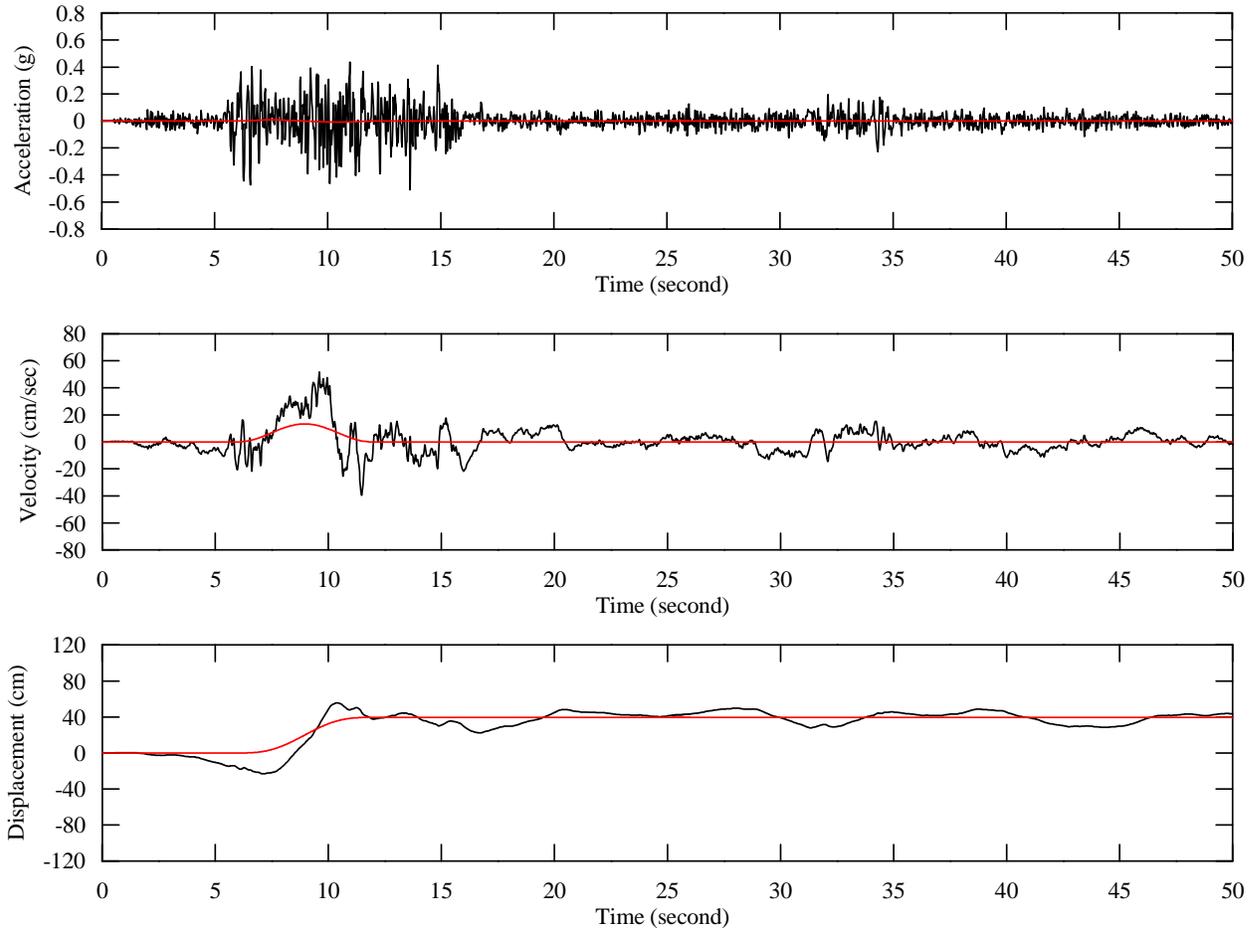


Figure 46: Fault parallel time histories including fling at crown of the tunnel, 1990 Manjil Earthquake

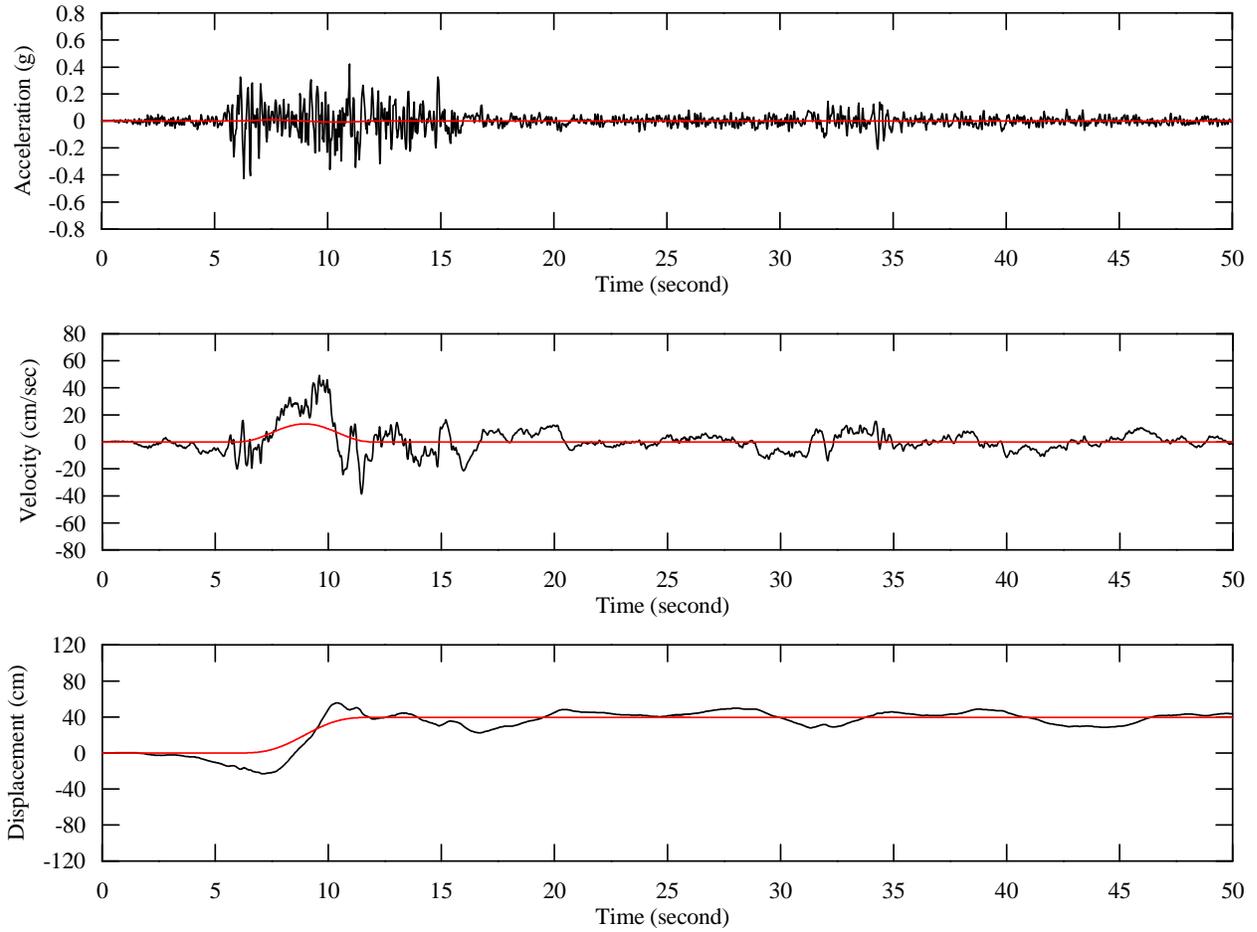


Figure 47: Fault parallel time histories including fling at top of side wall, 1990 Manjil Earthquake

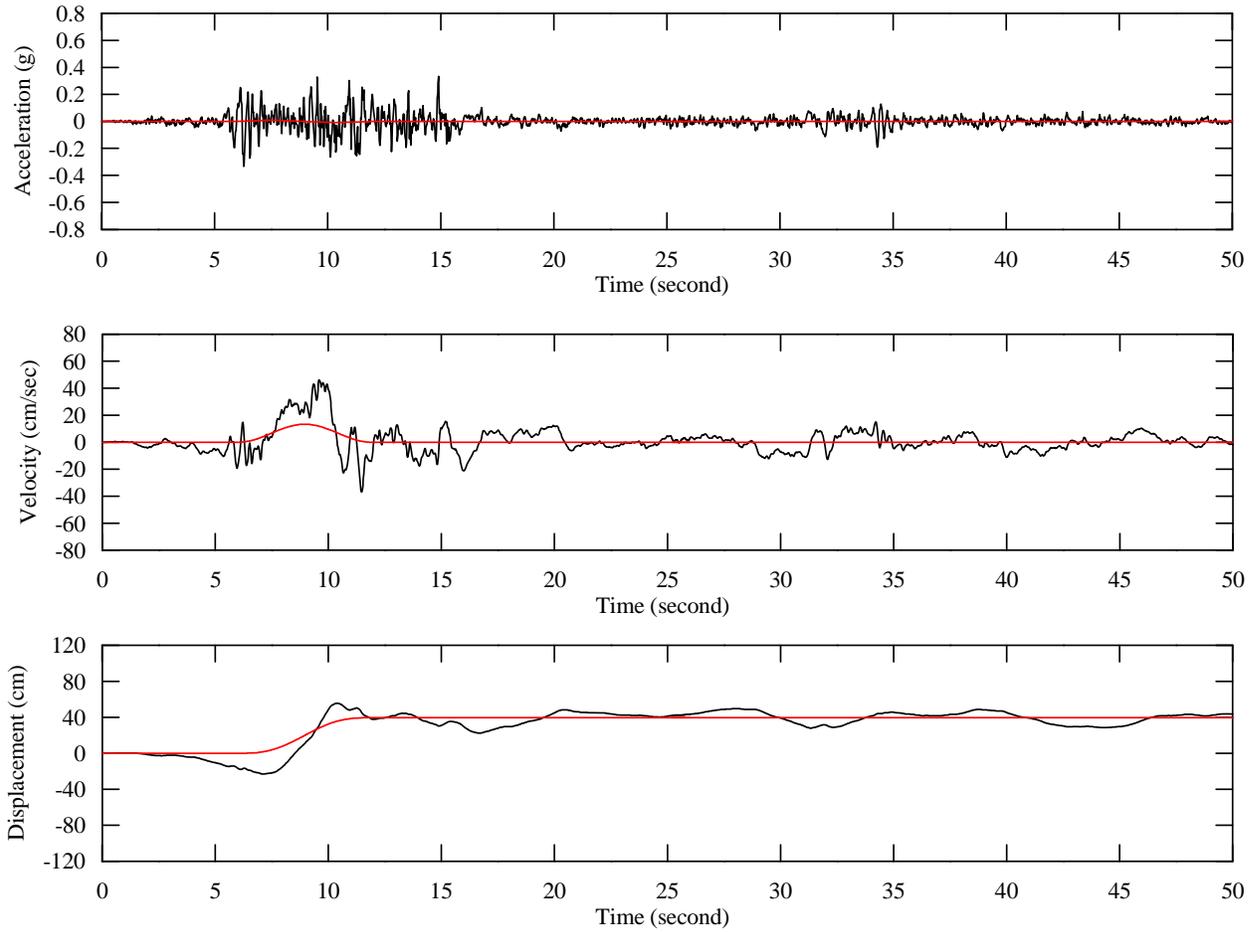


Figure 48: Fault parallel time histories including fling at invert of the tunnel, 1990 Manjil Earthquake

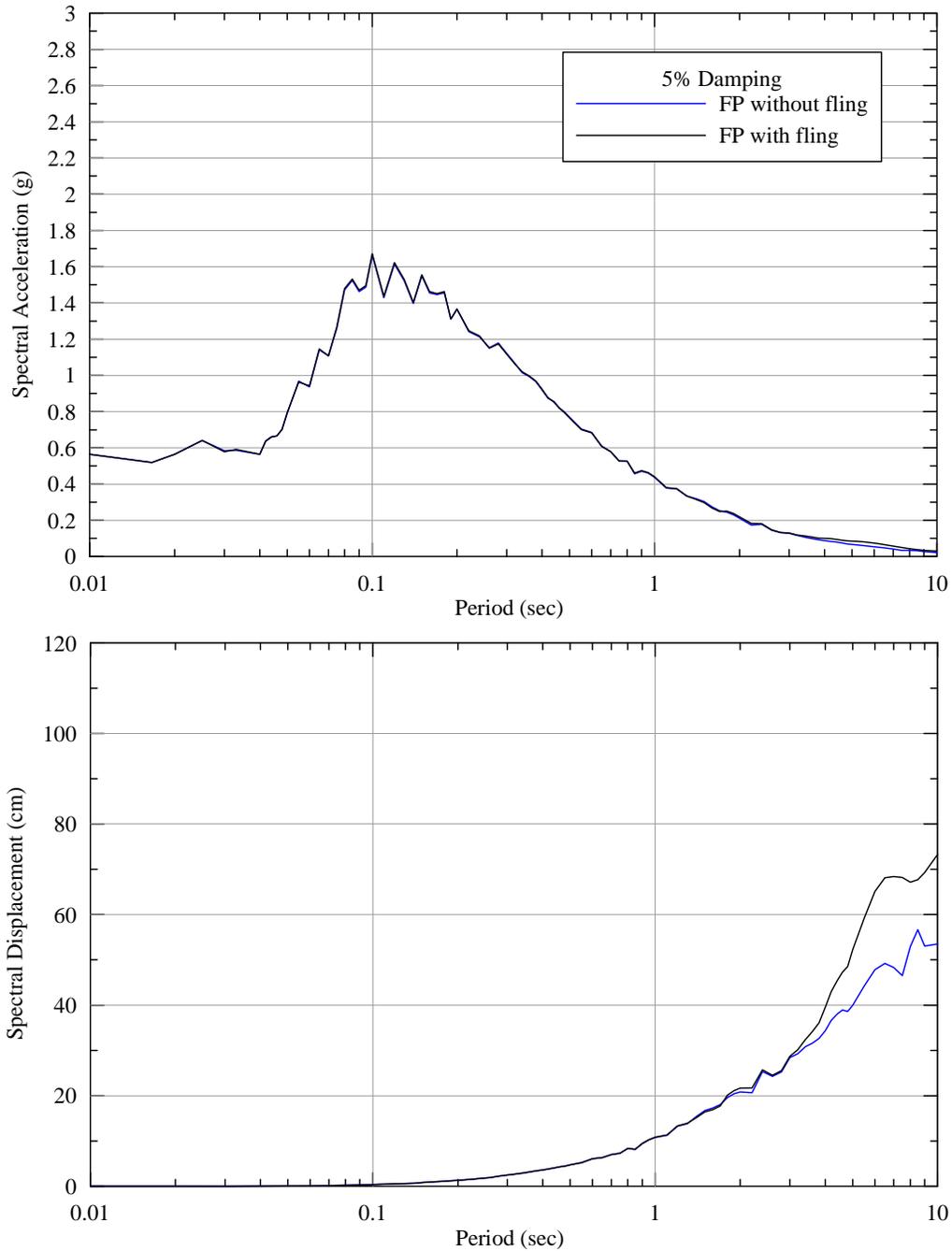


Figure 49: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1990 Manjil Earthquake

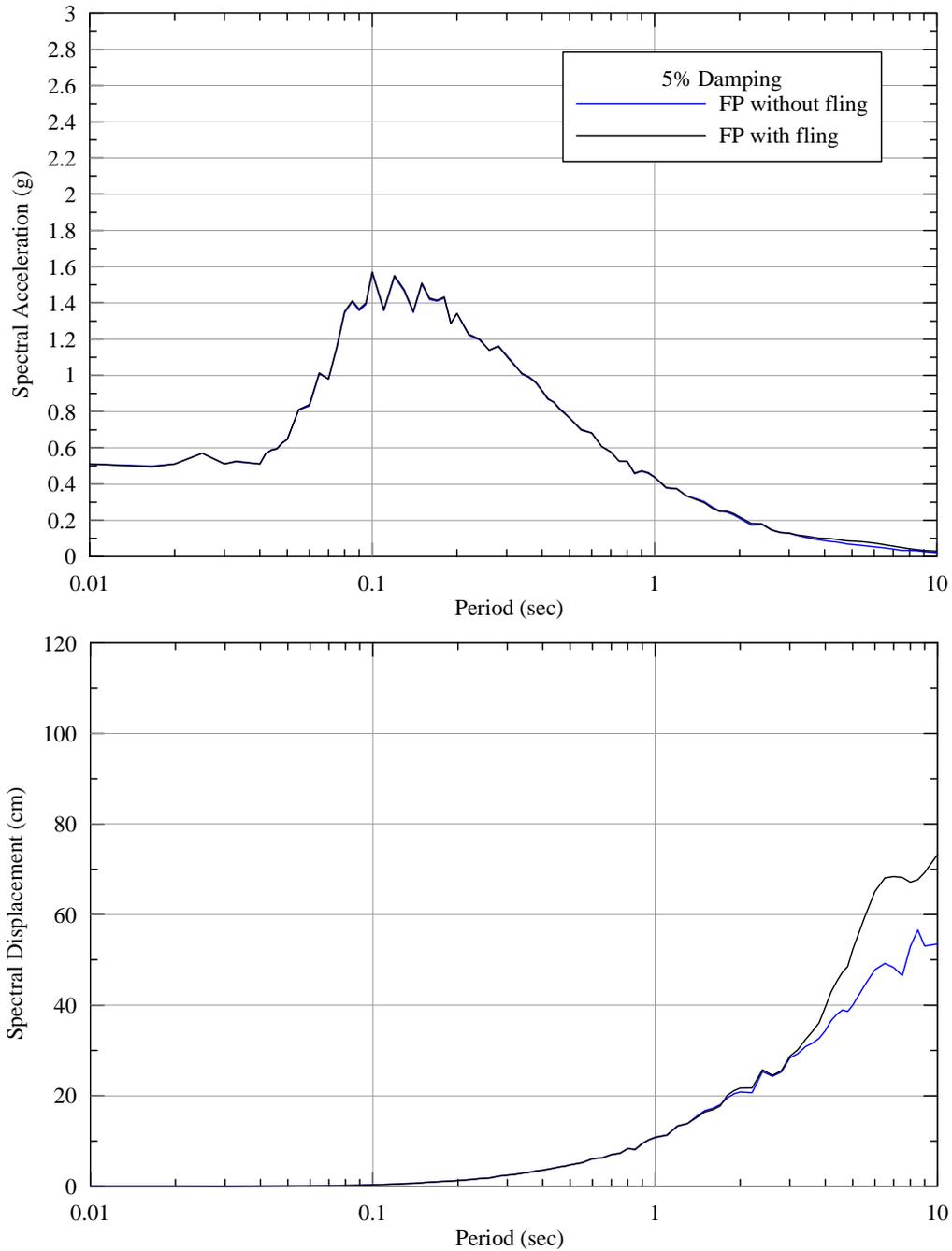


Figure 50: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1990 Manjil Earthquake

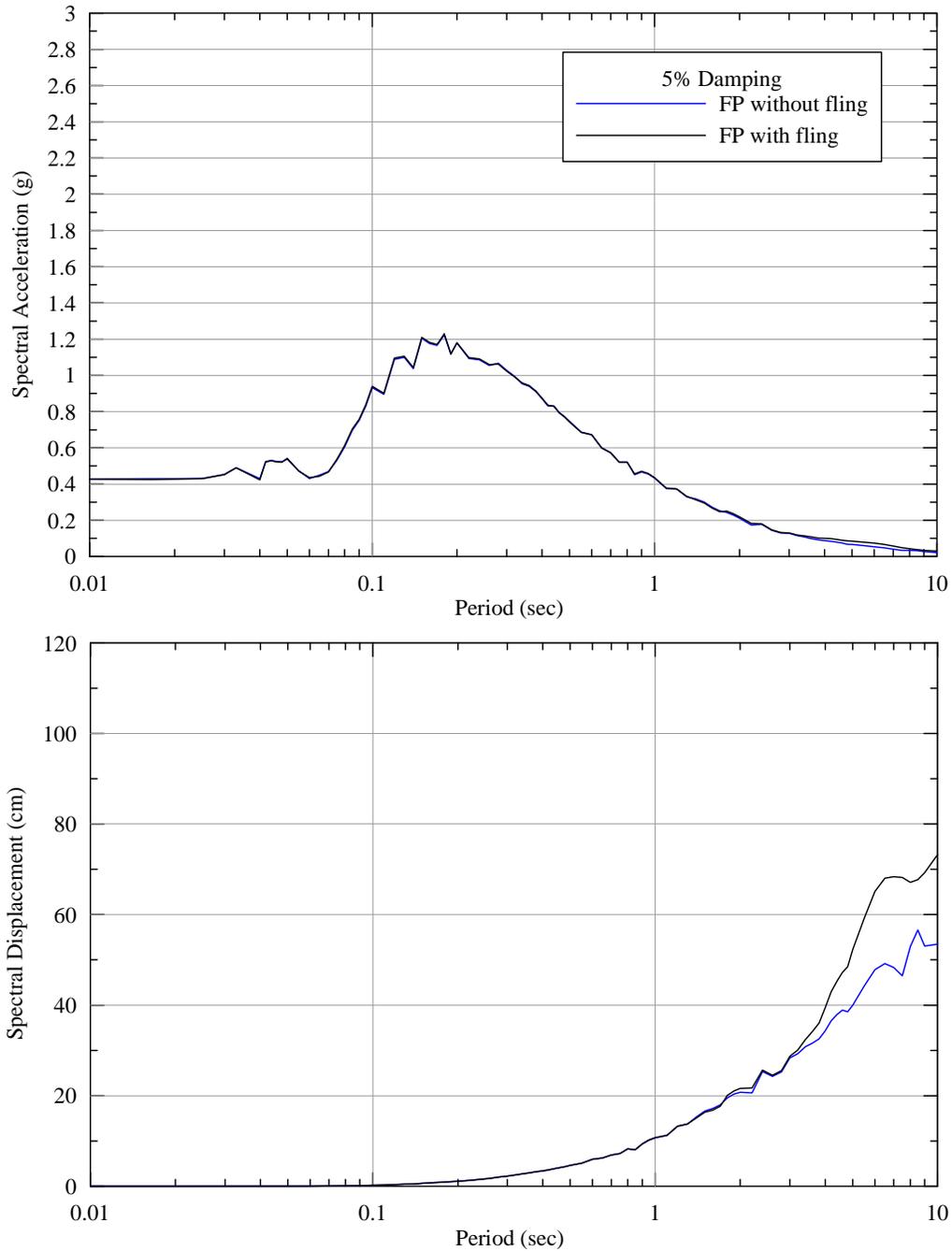


Figure 51: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1990 Manjil Earthquake

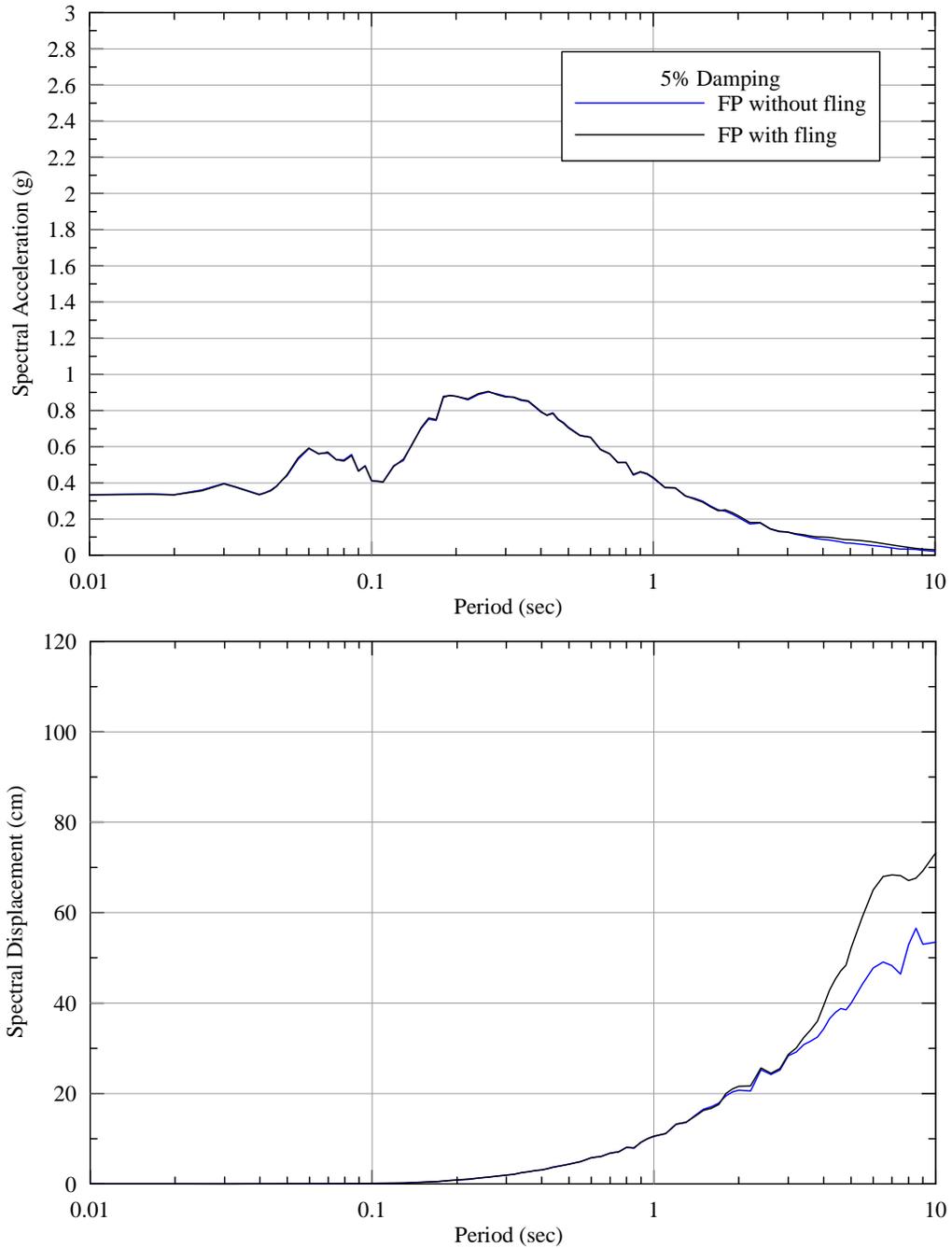


Figure 52: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1990 Manjil Earthquake

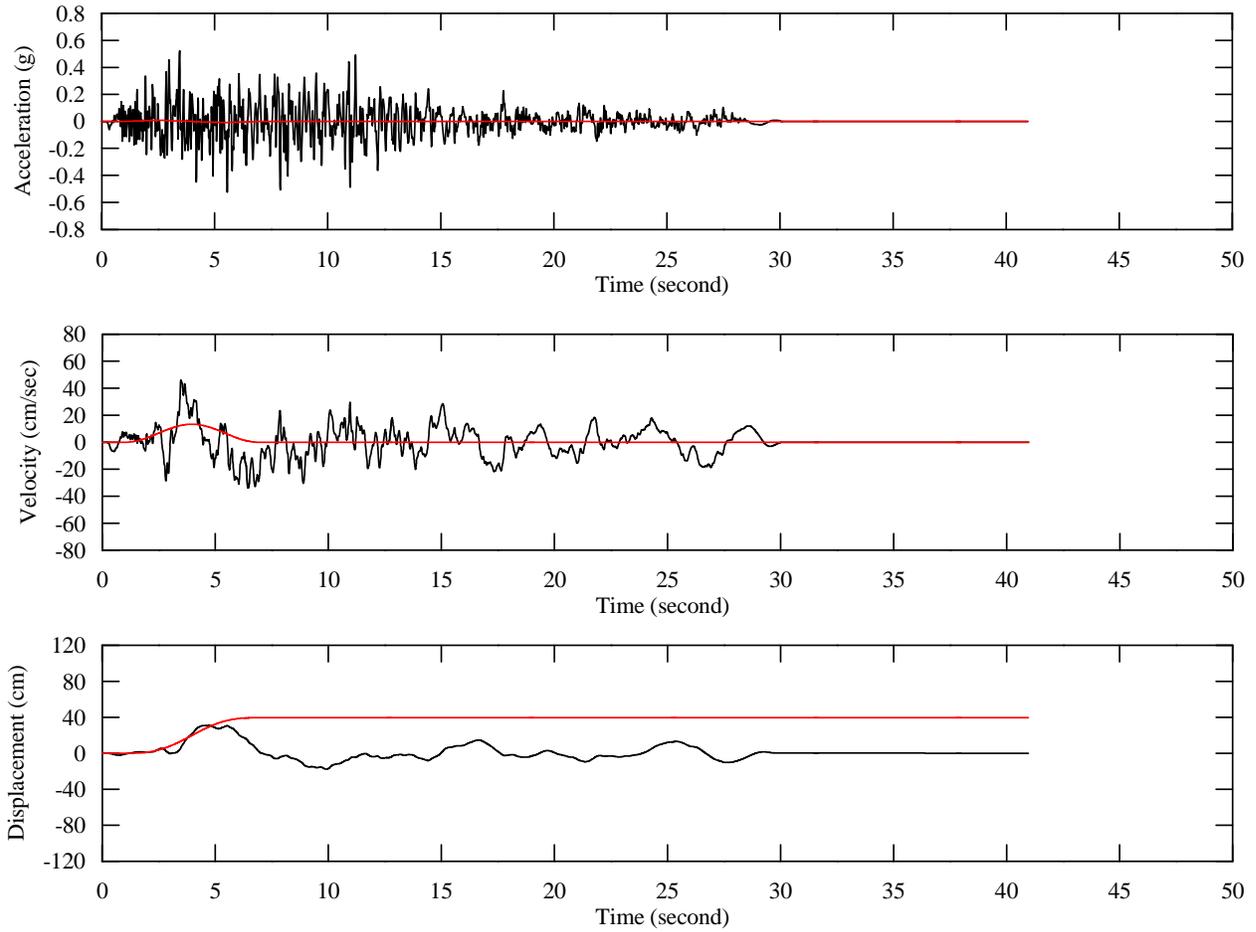


Figure 53: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1999 Kocaeli Earthquake

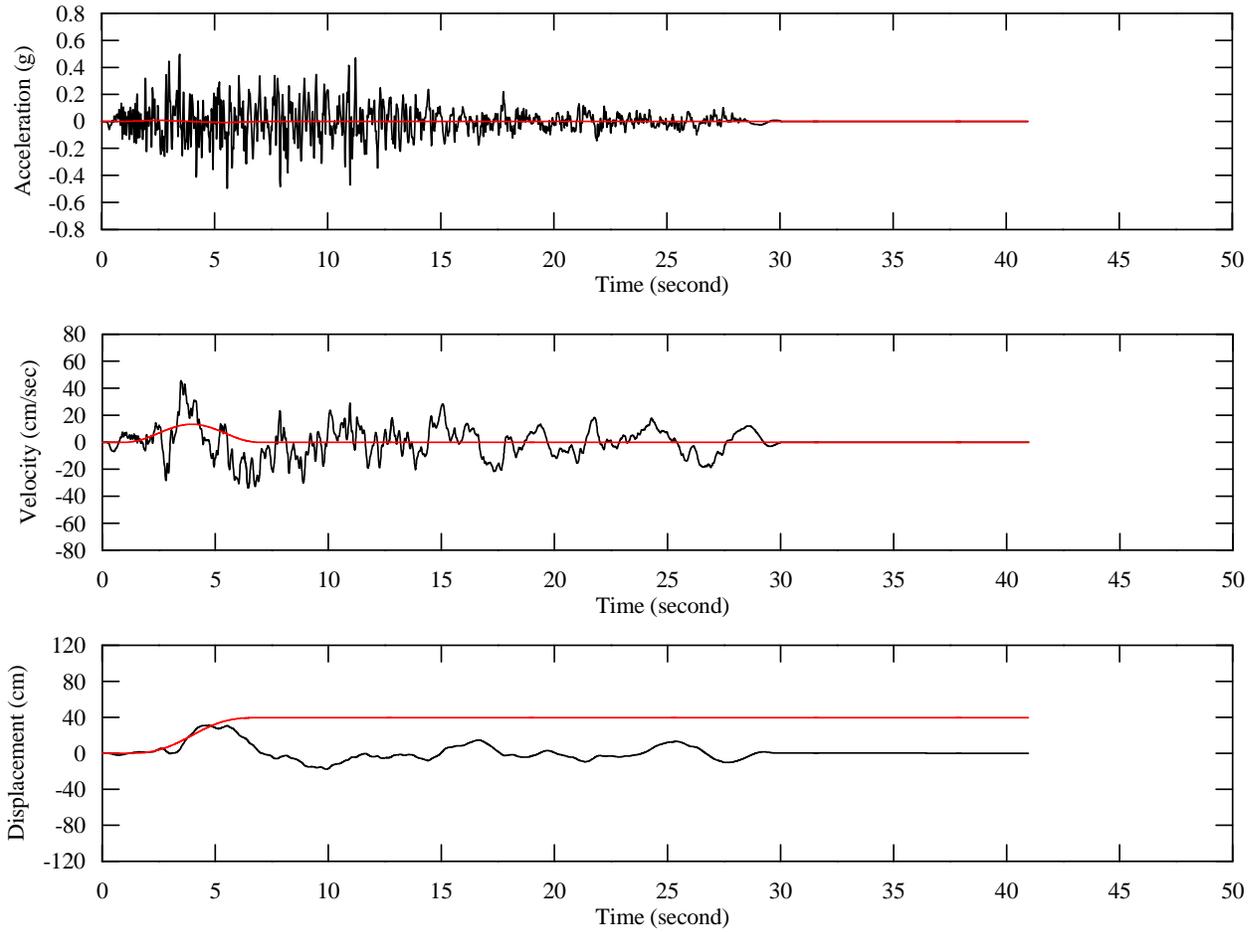


Figure 54: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1999 Kocaeli Earthquake

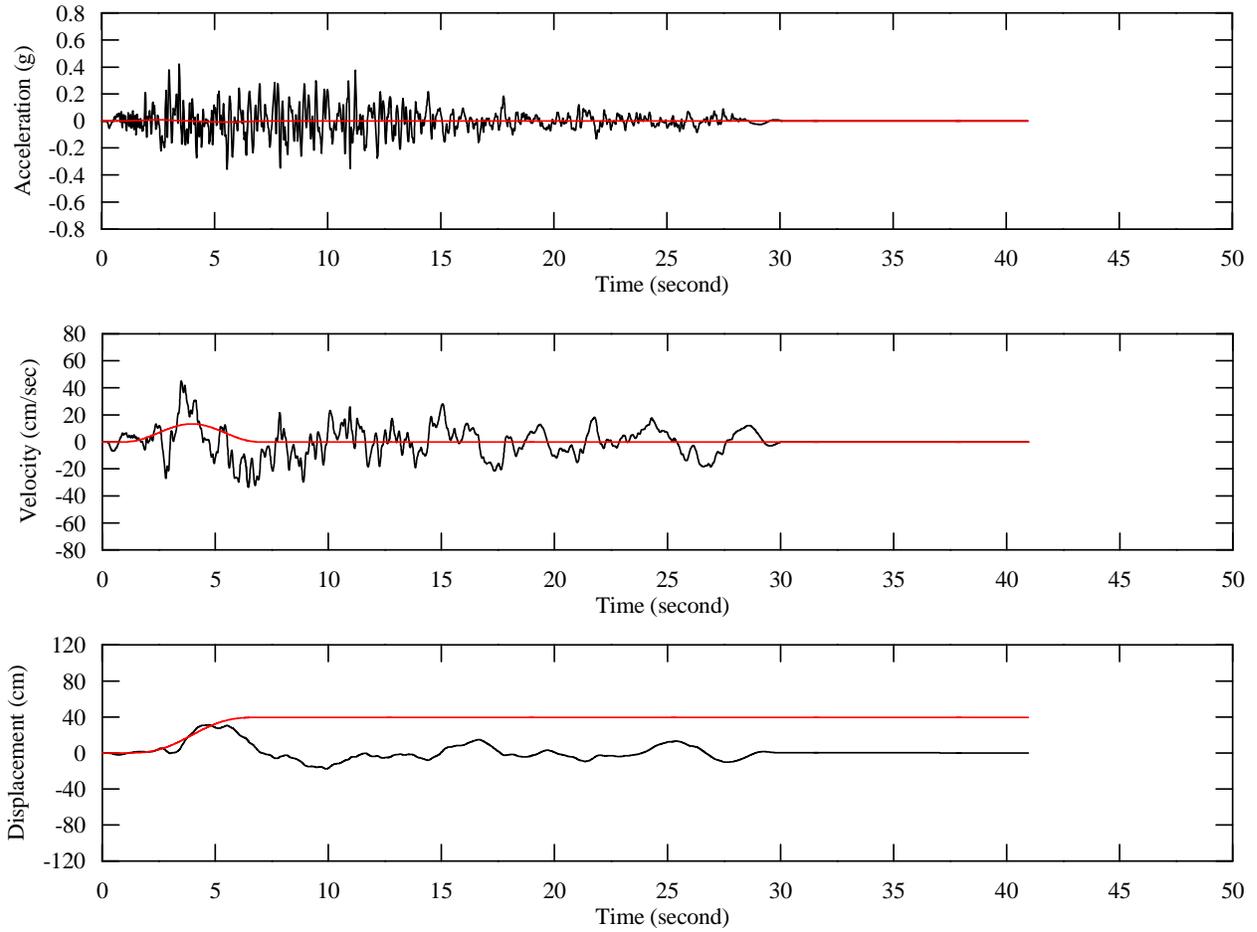


Figure 55: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1999 Kocaeli Earthquake

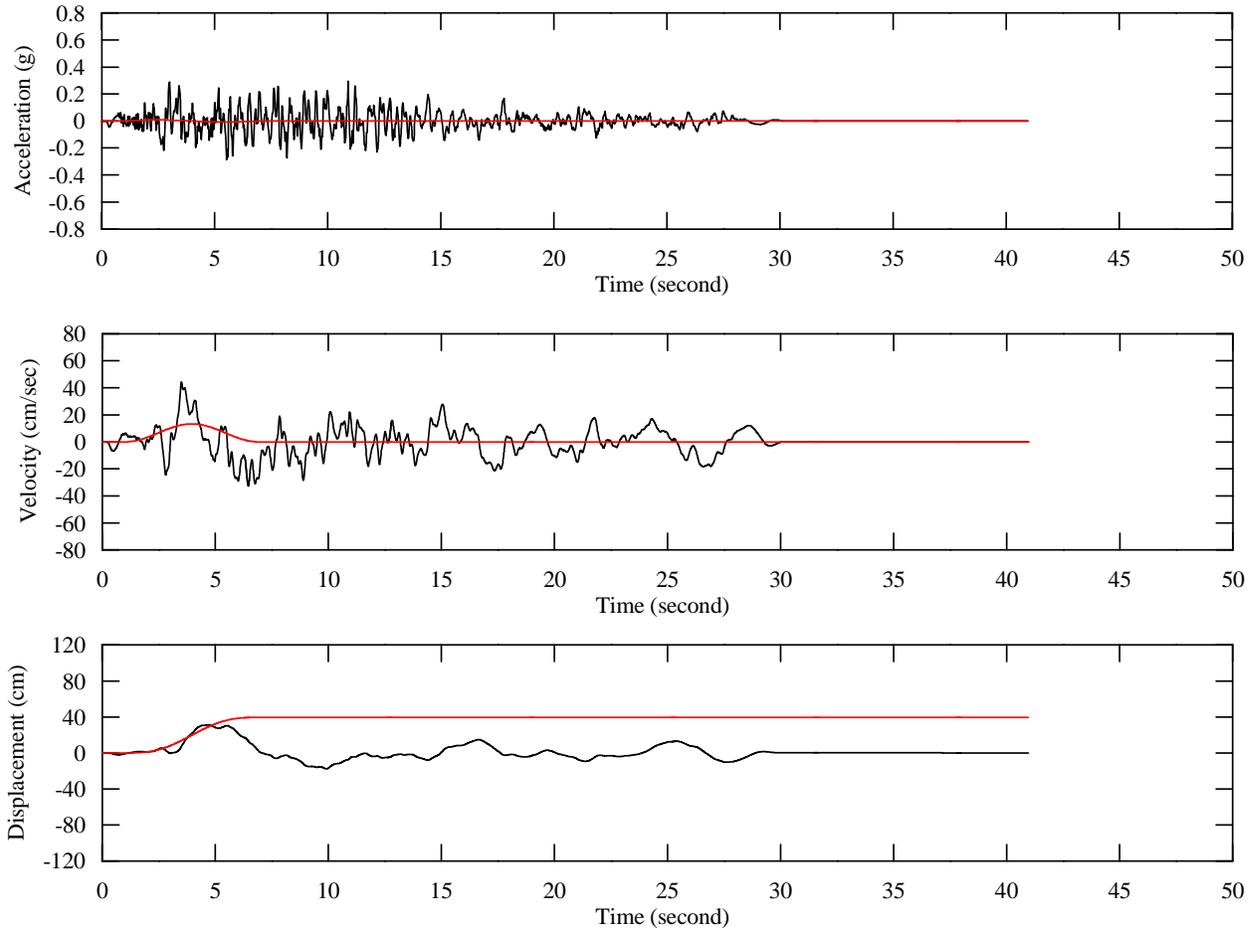


Figure 56: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1999 Kocaeli Earthquake

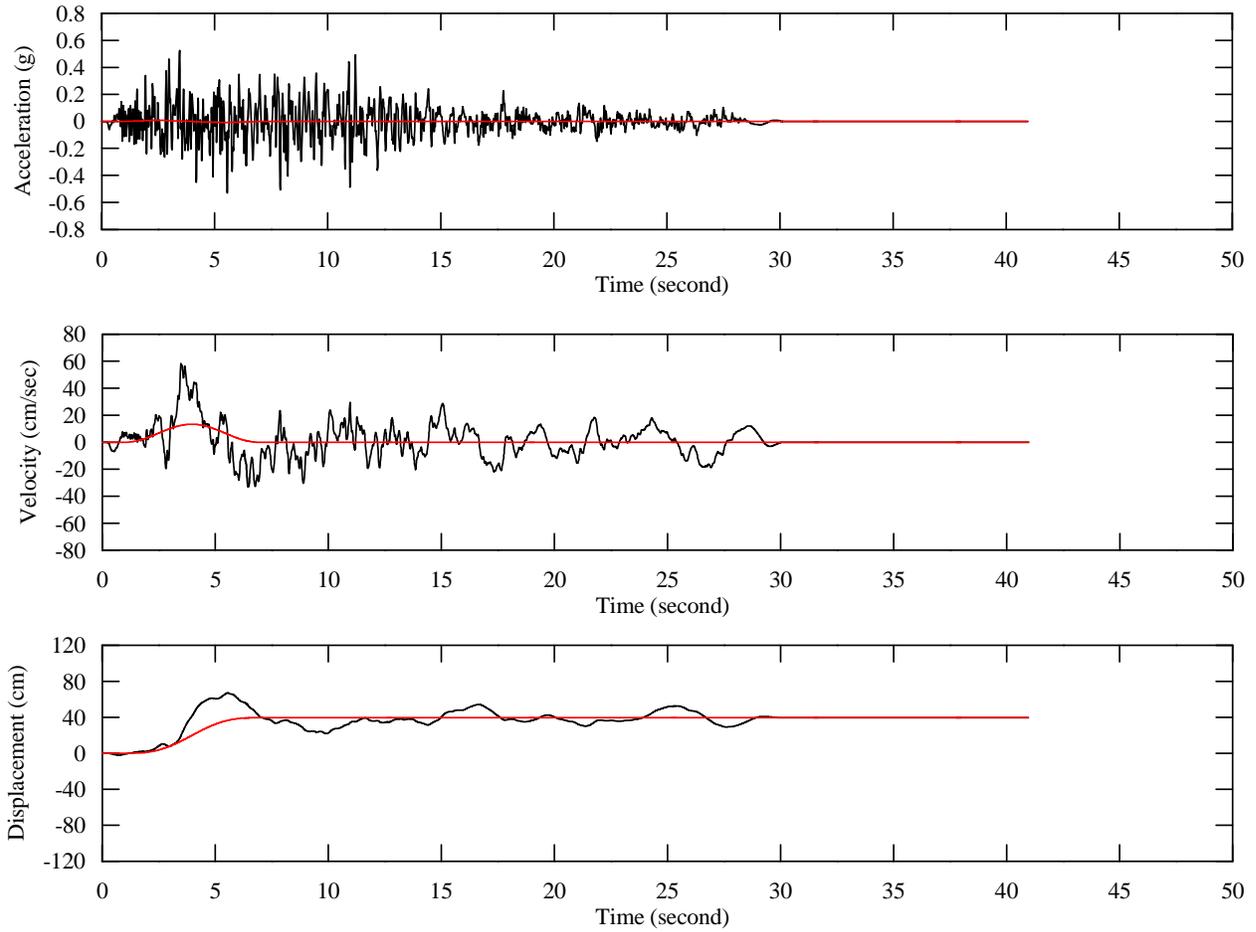


Figure 57: Fault parallel time histories including fling at ground surface, 1999 Kocaeli Earthquake

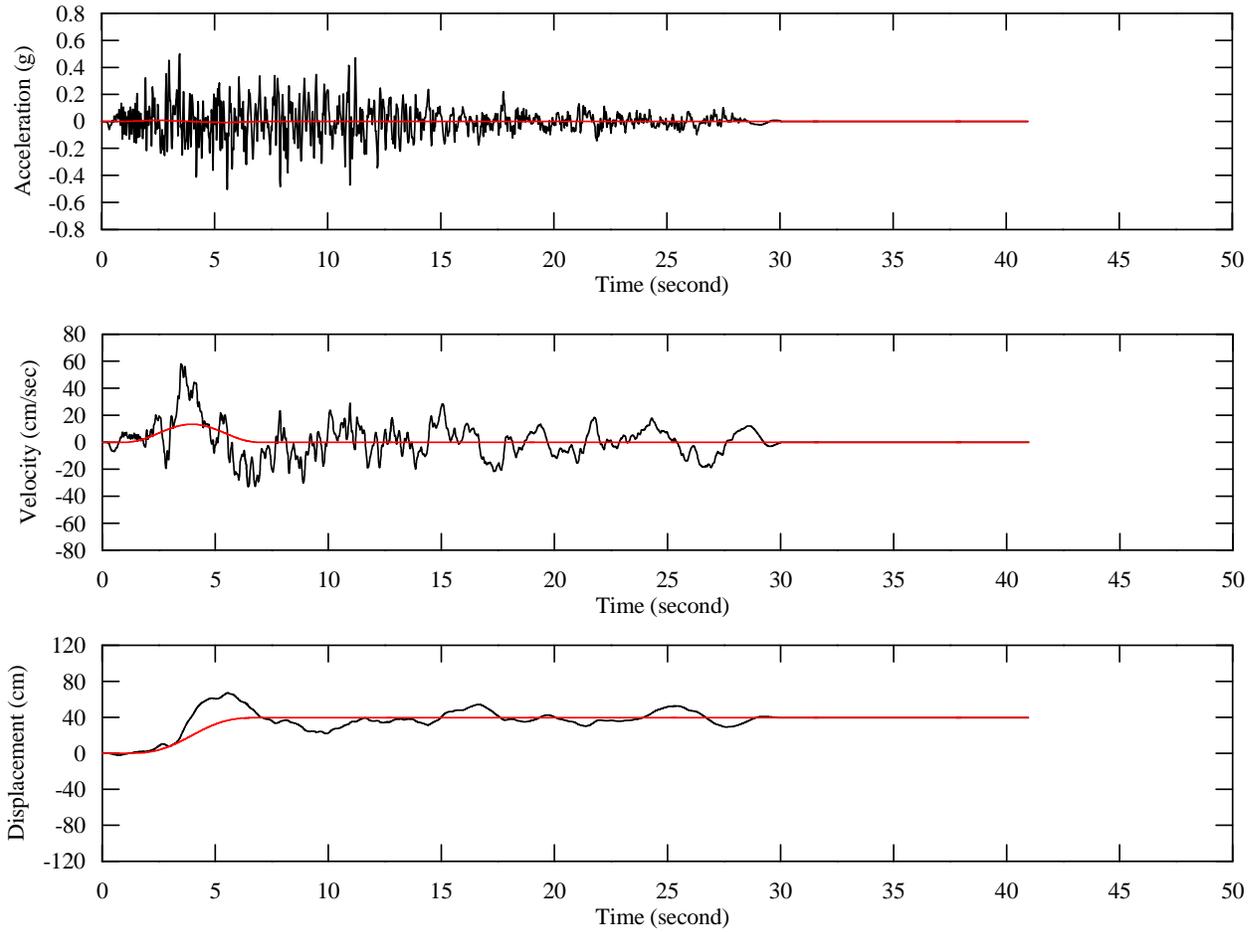


Figure 58: Fault parallel time histories including fling at crown of the tunnel, 1999 Kocaeli Earthquake

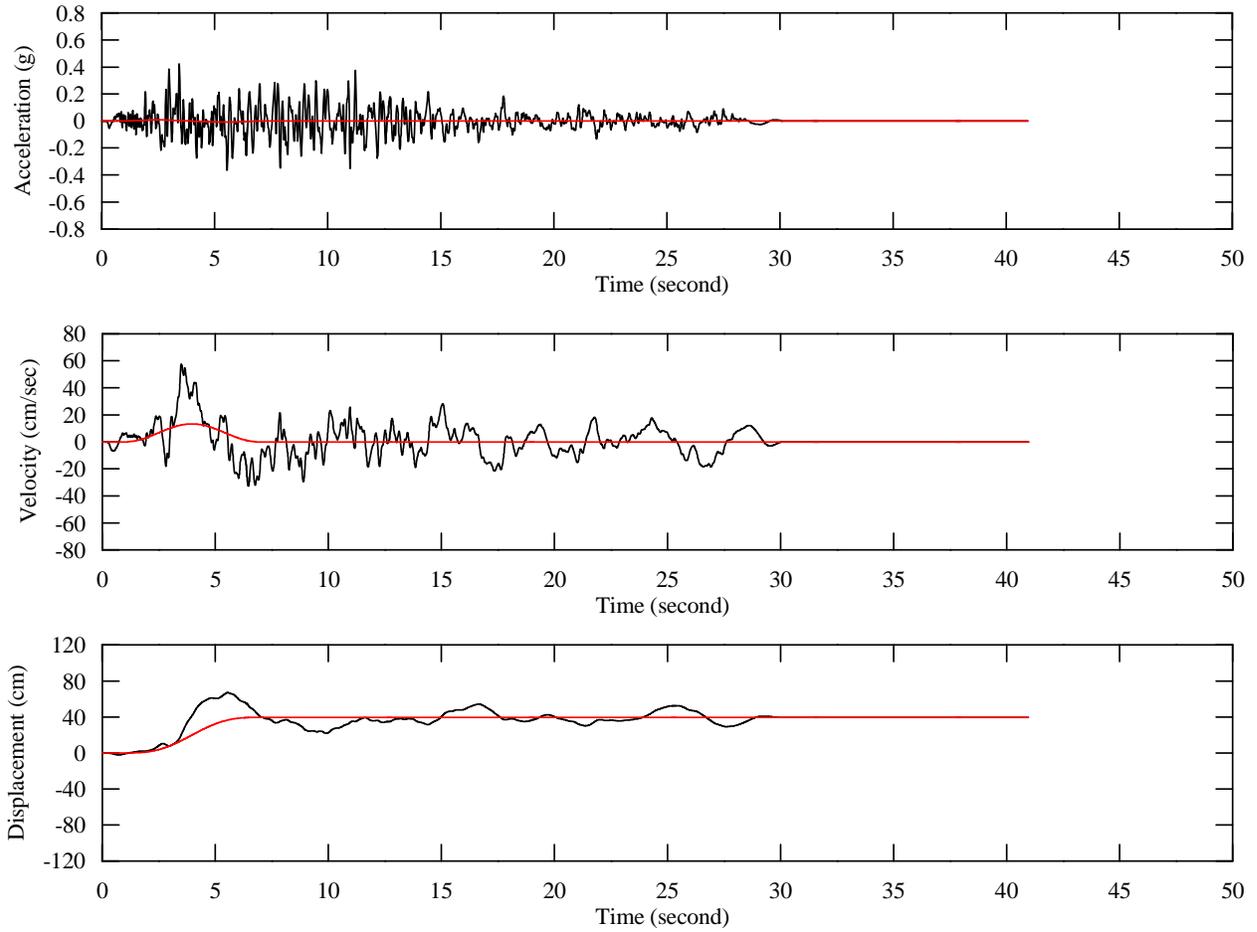


Figure 59: Fault parallel time histories including fling at top of side wall, 1999 Kocaeli Earthquake

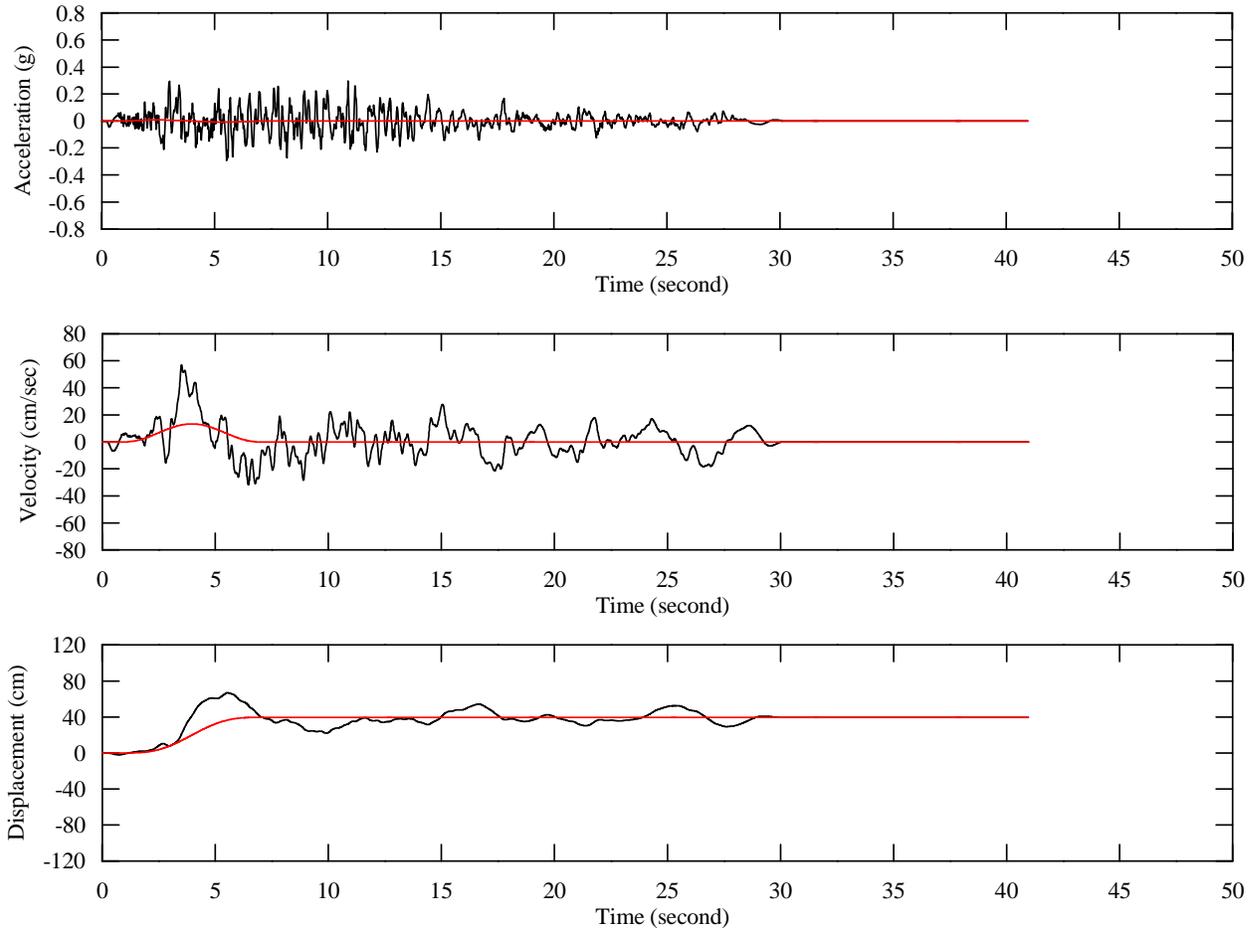


Figure 60: Fault parallel time histories including fling at invert of the tunnel, 1999 Kocaeli Earthquake

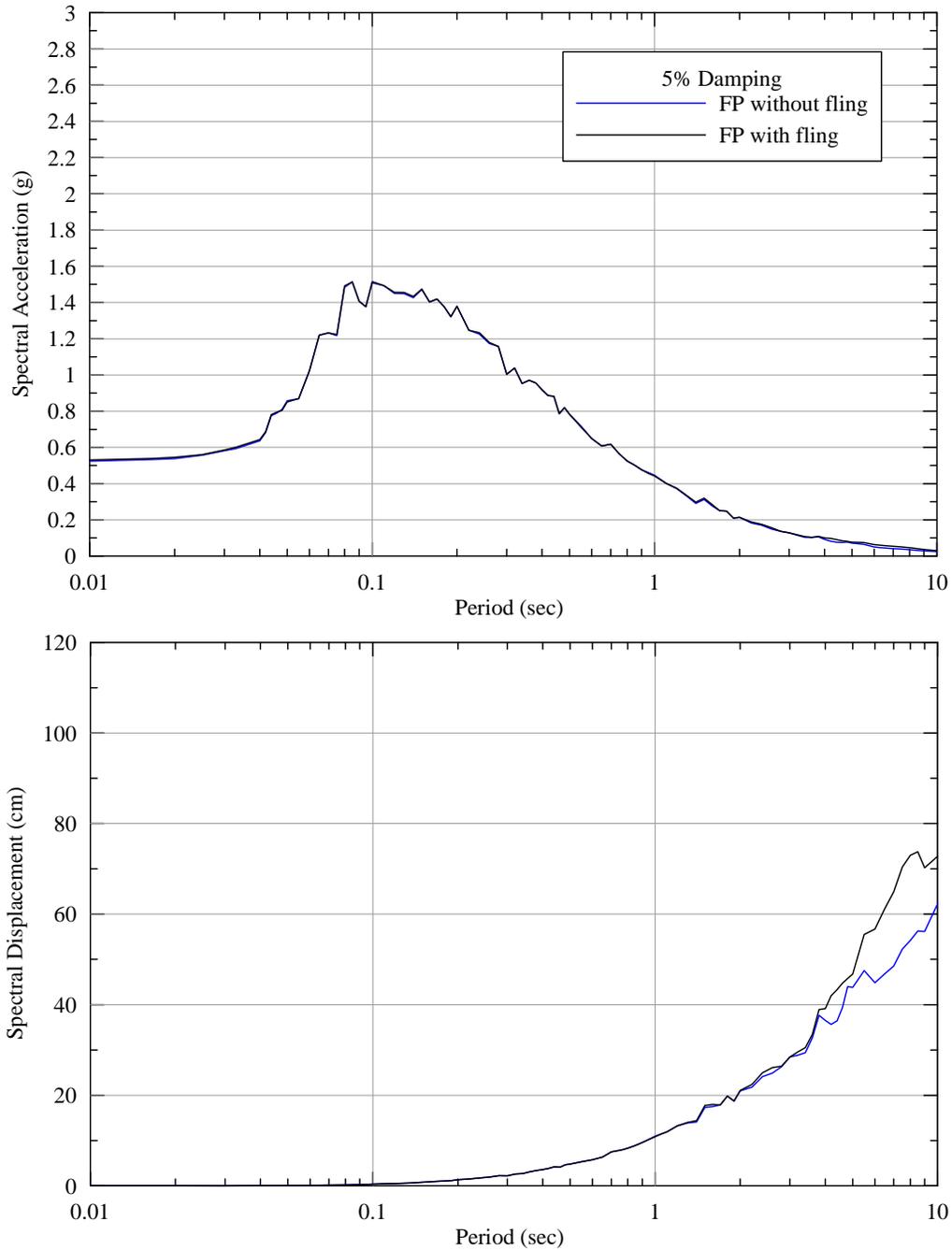


Figure 61: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1999 Kocaeli Earthquake

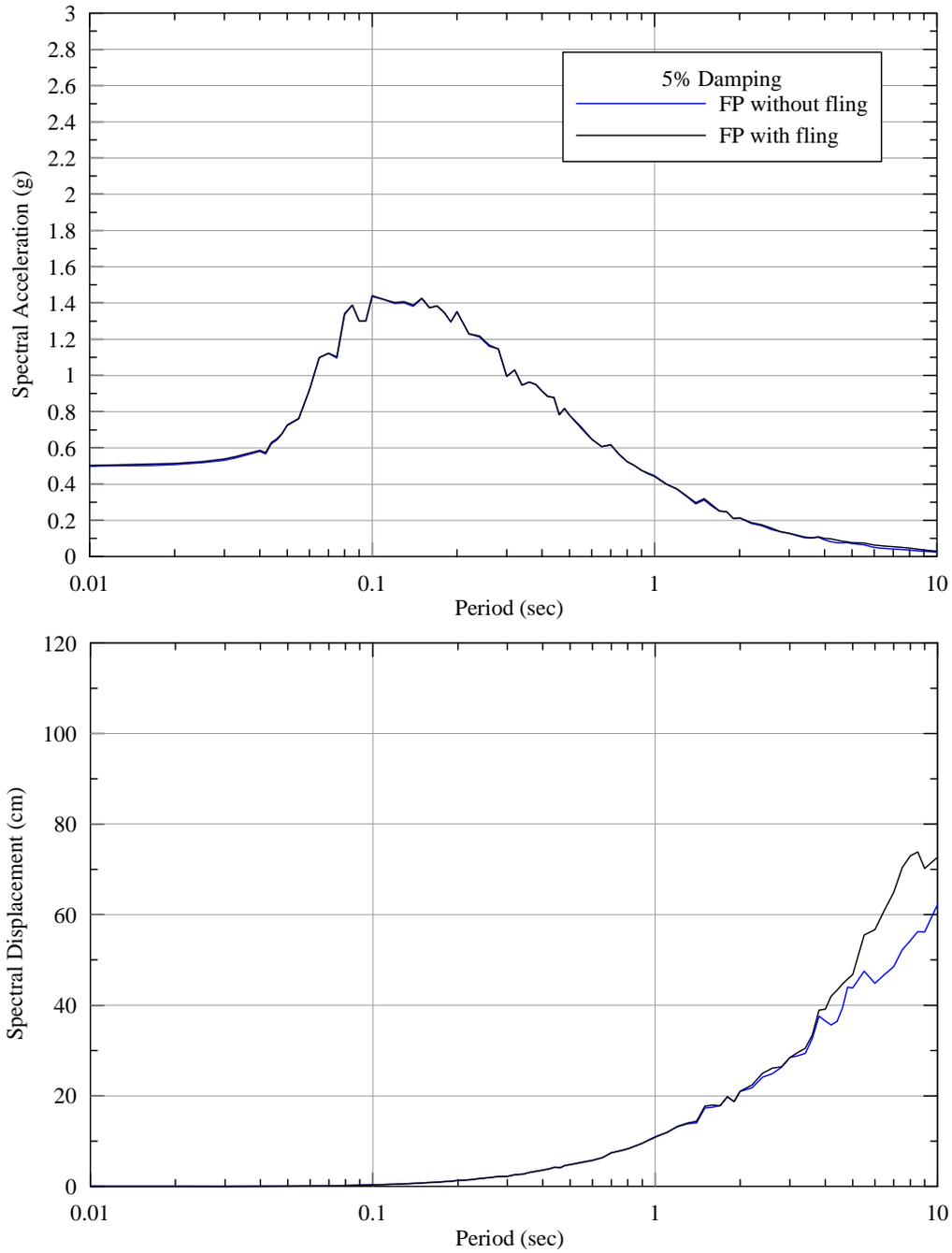


Figure 62: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1999 Kocaeli Earthquake

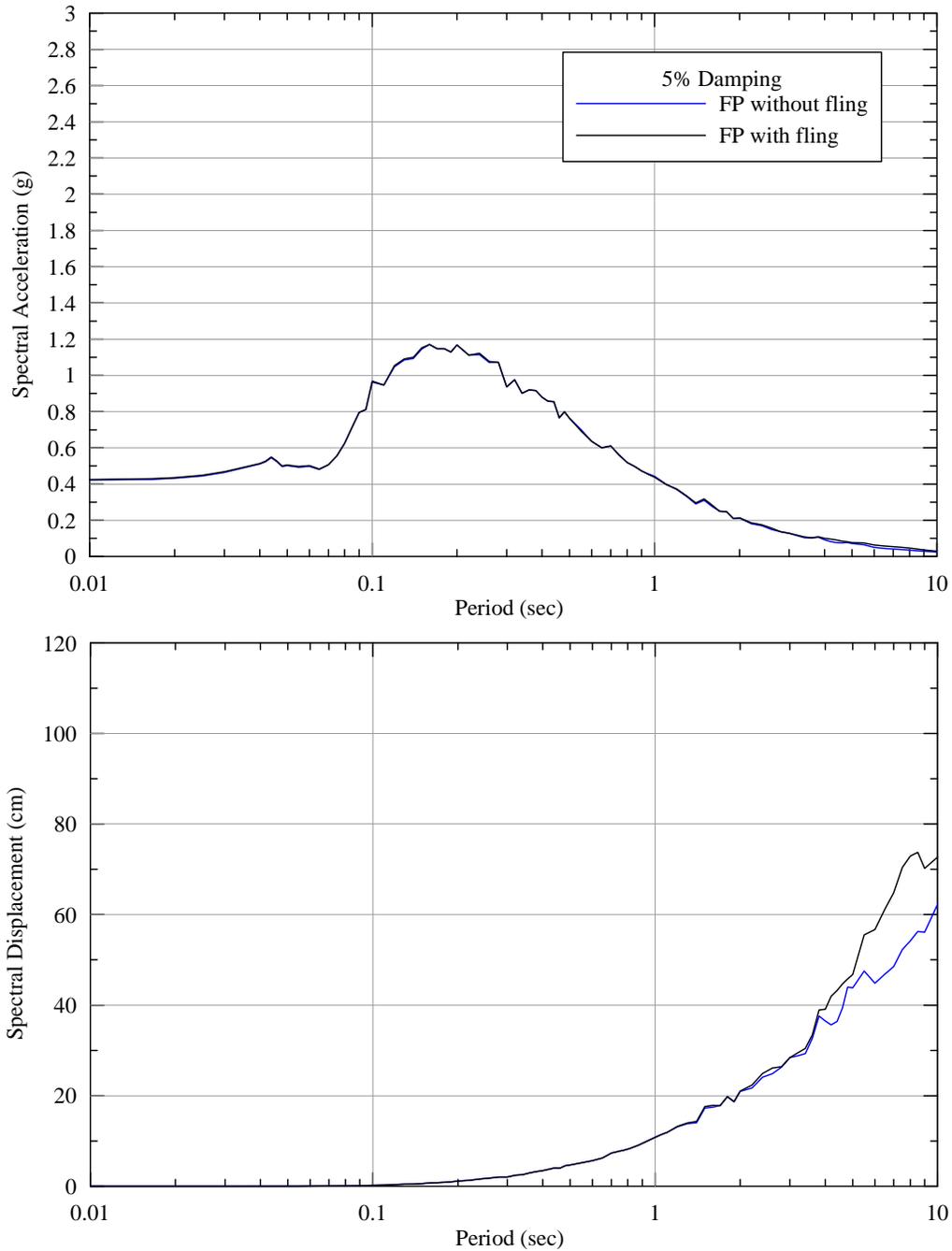


Figure 63: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1999 Kocaeli Earthquake

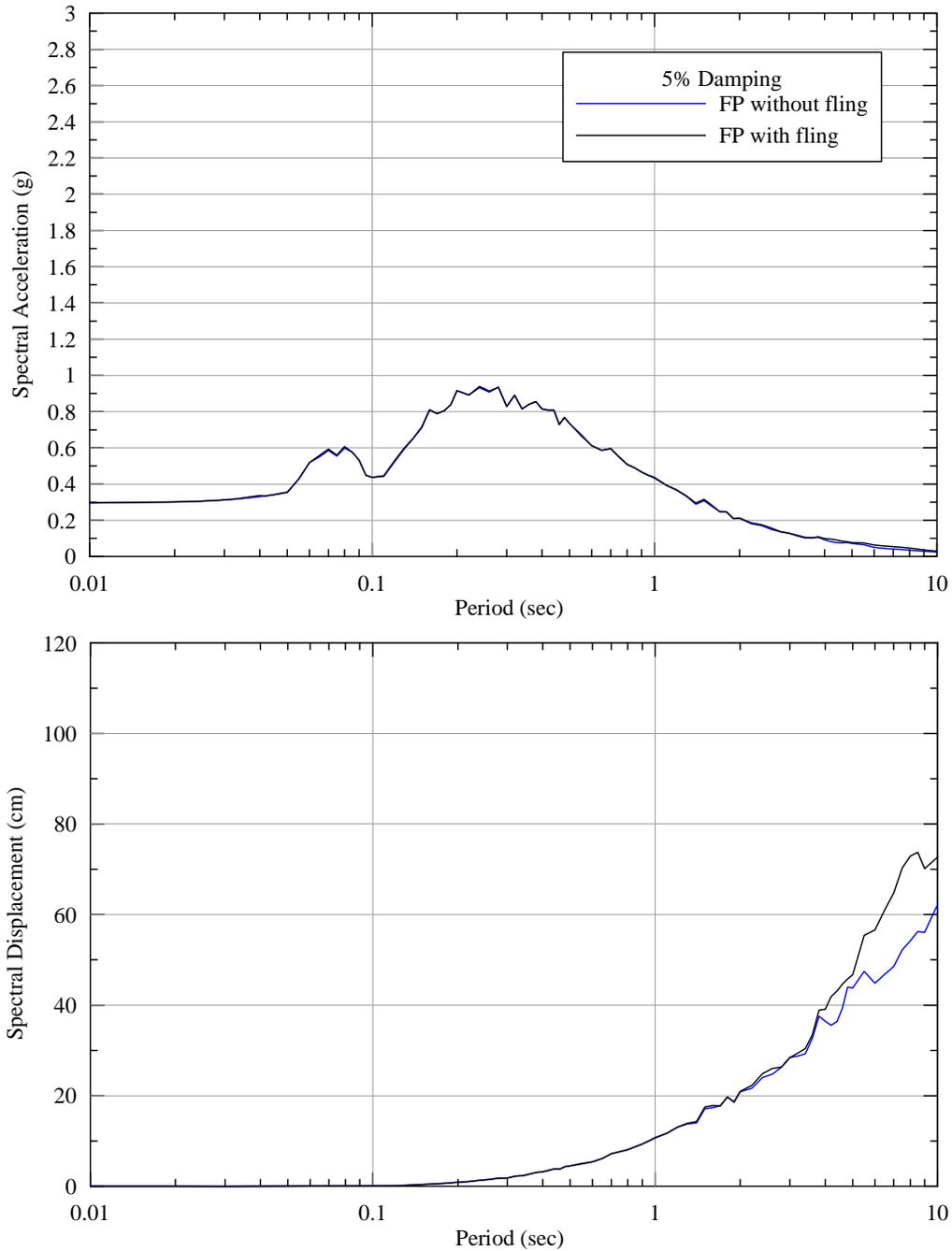


Figure 64: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1999 Kocaeli Earthquake

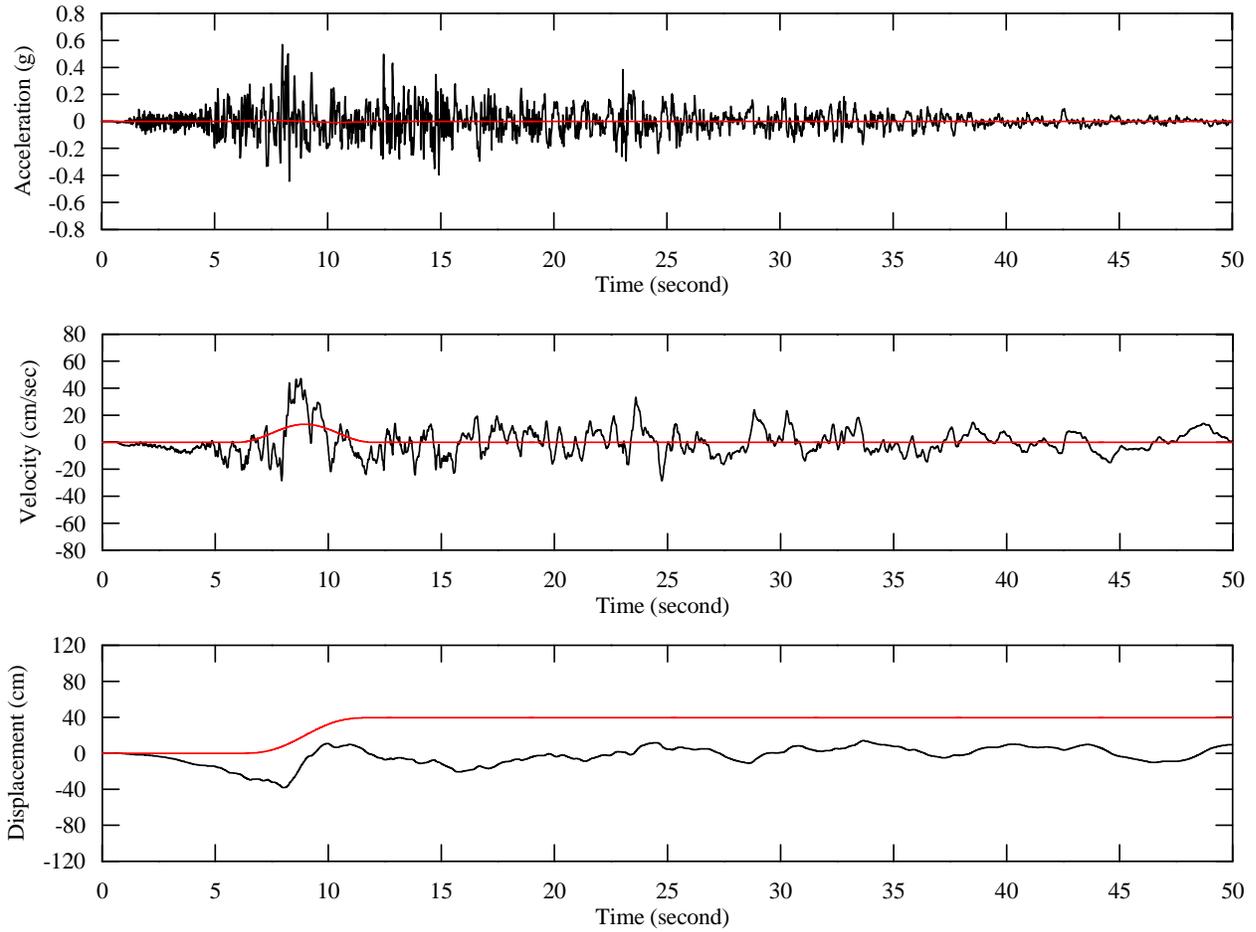


Figure 65: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

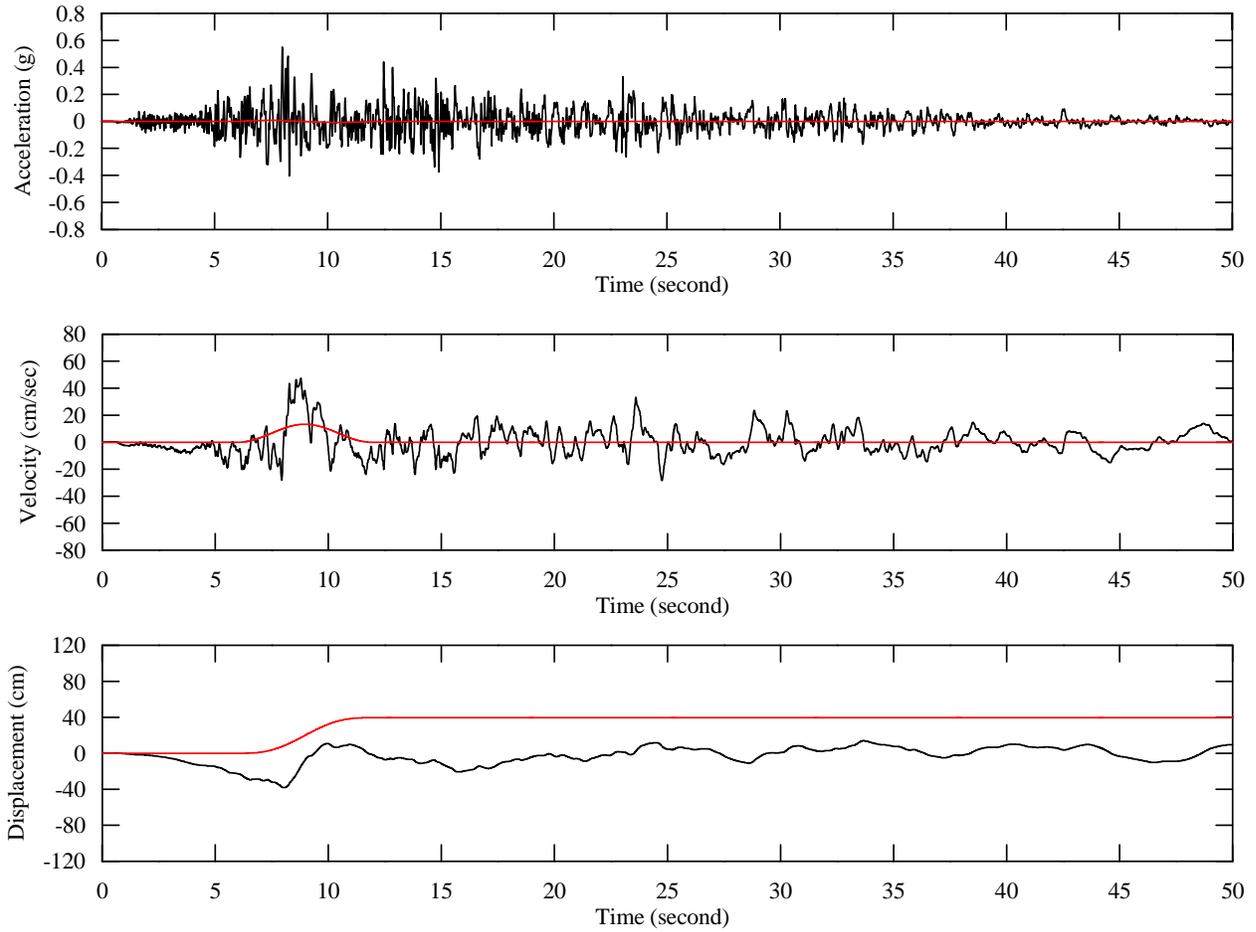


Figure 66: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

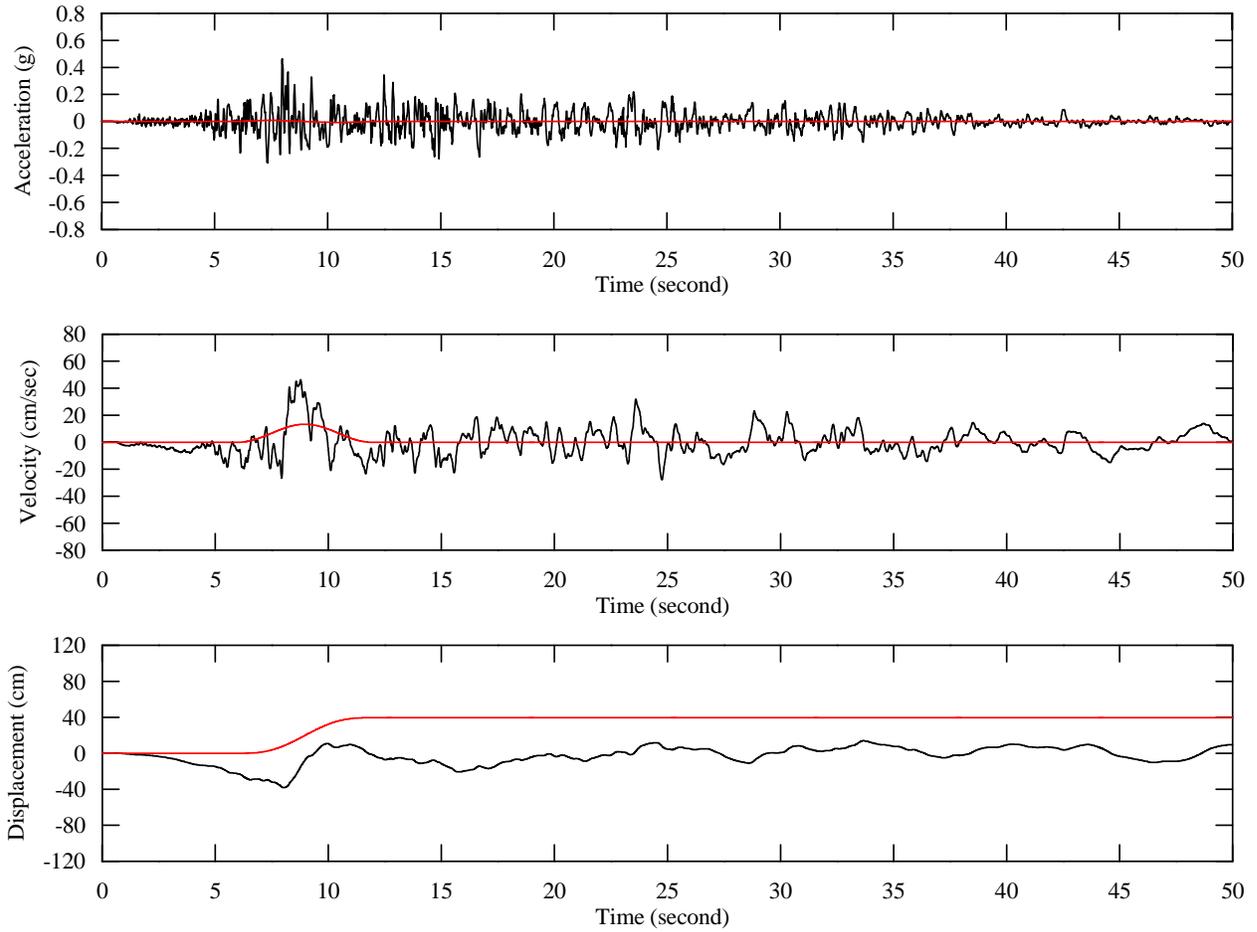


Figure 67: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

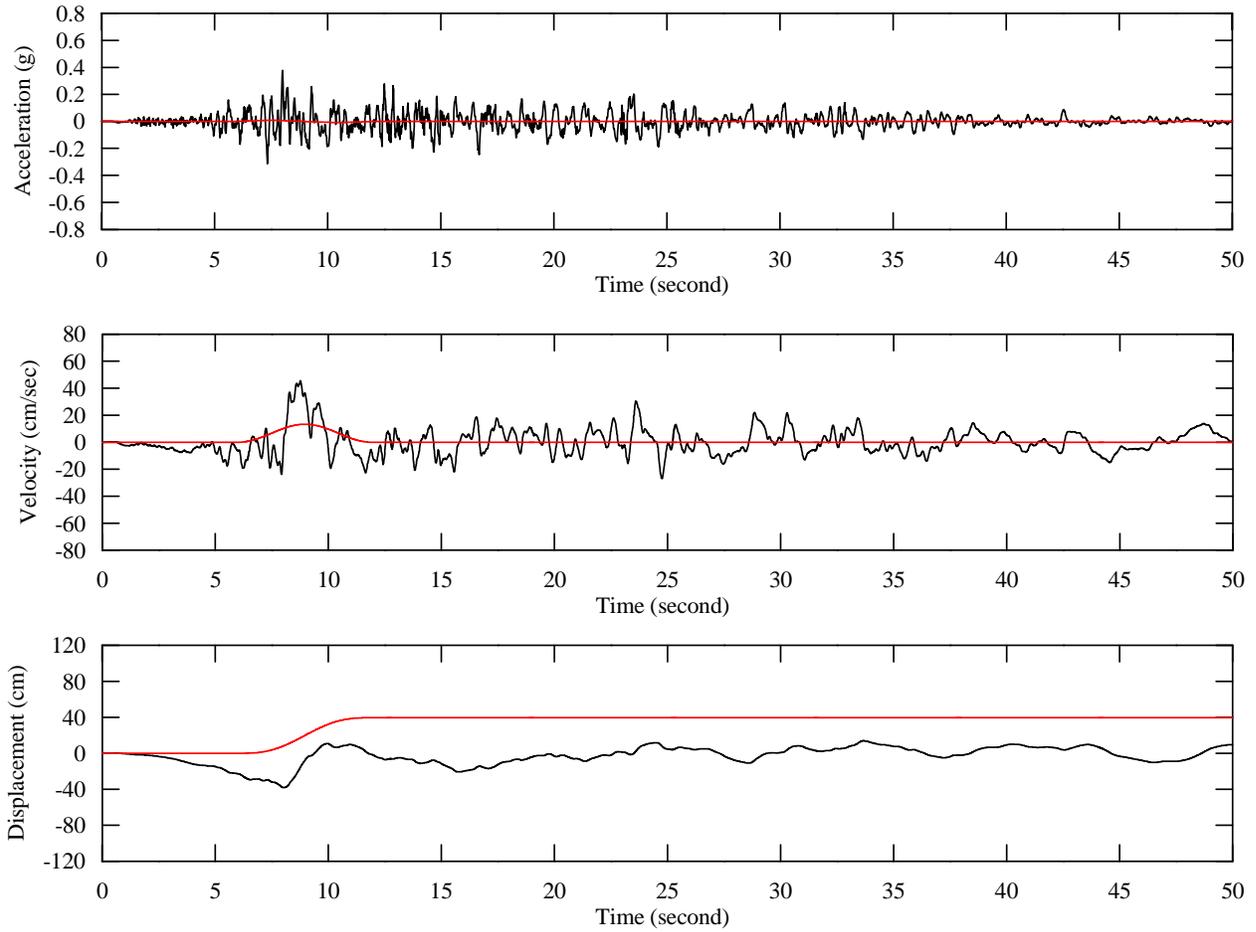


Figure 68: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

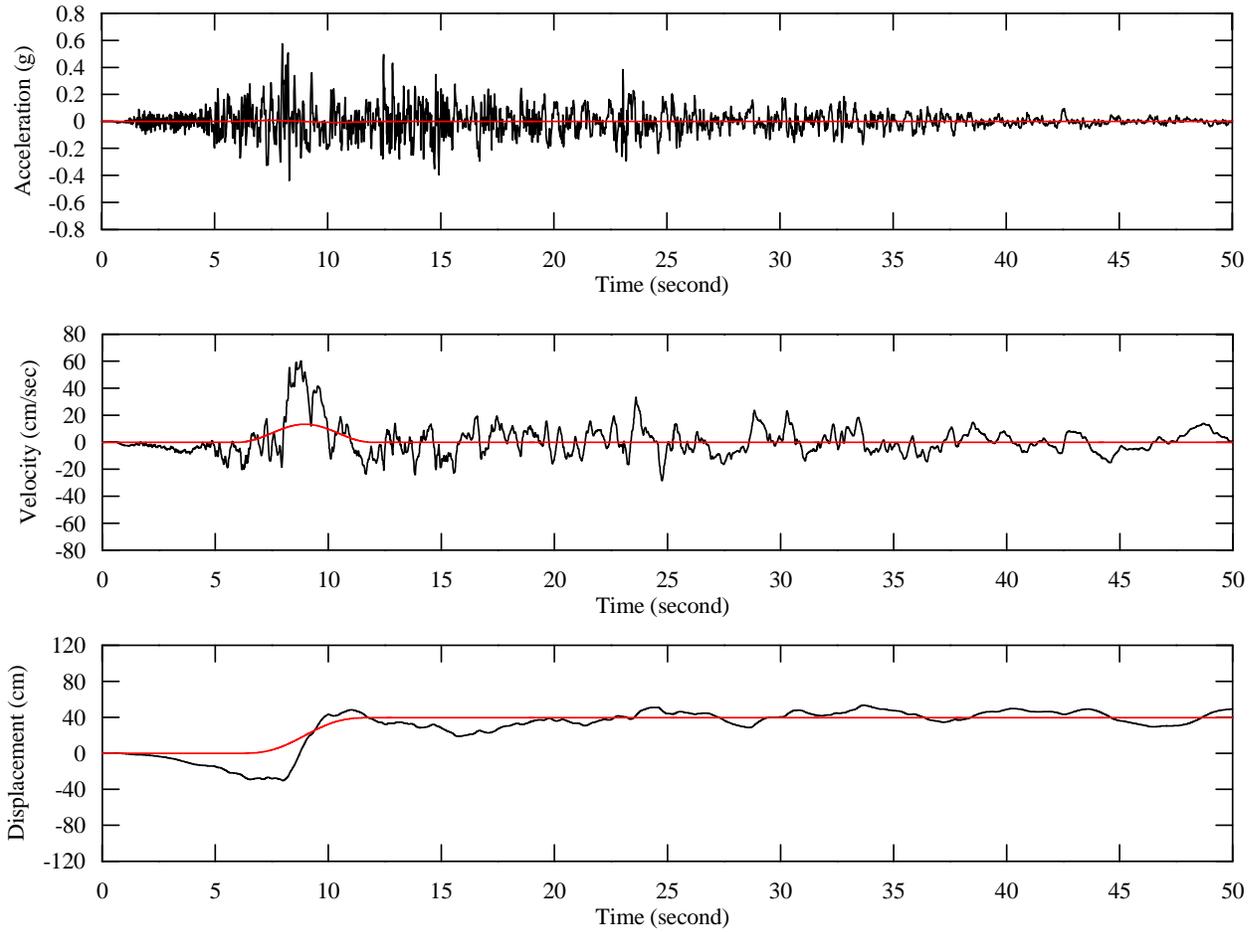


Figure 69: Fault parallel time histories including fling at ground surface, 1999 Chi-Chi Earthquake

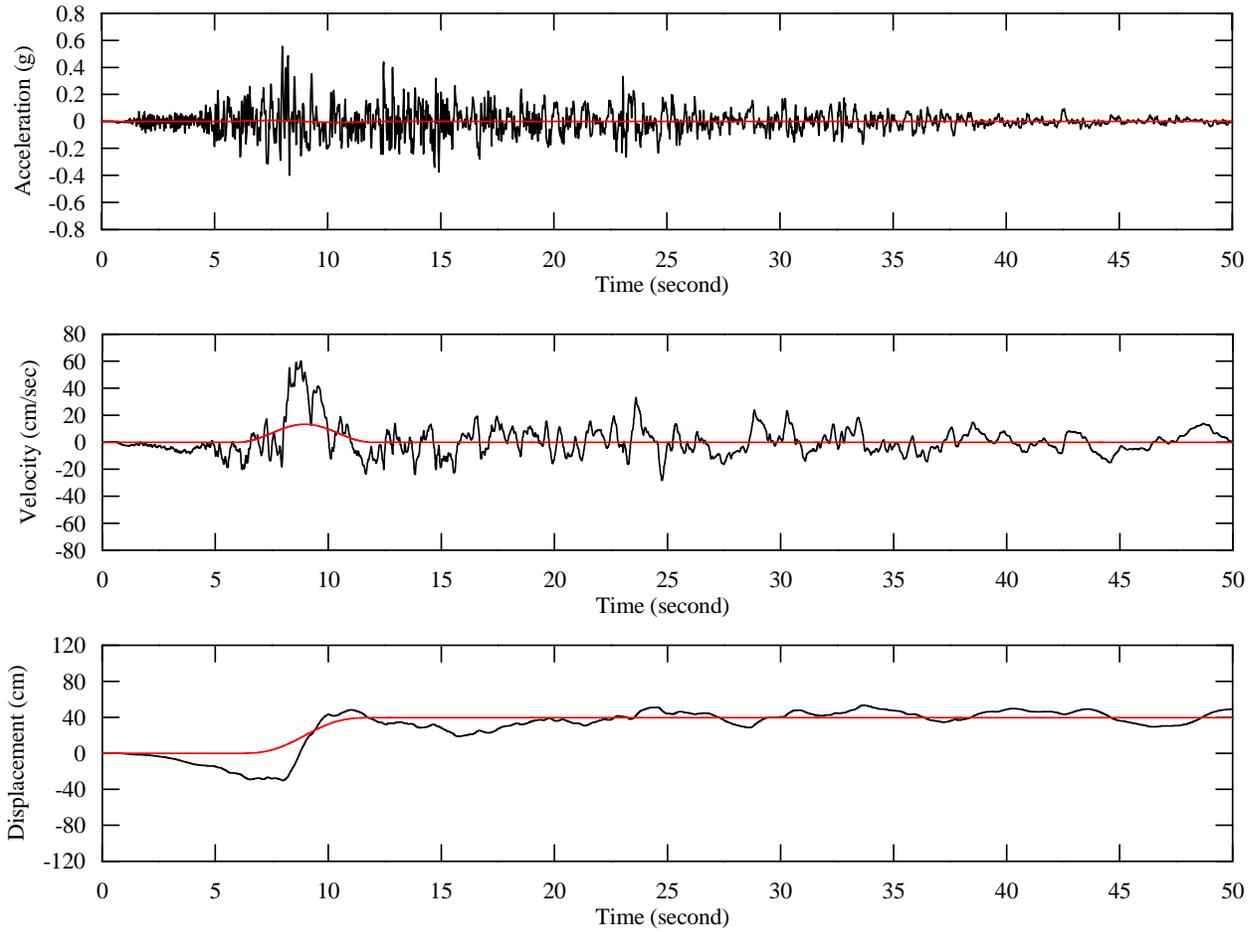


Figure 70: Fault parallel time histories including fling at crown of the tunnel, 1999 Chi-Chi Earthquake

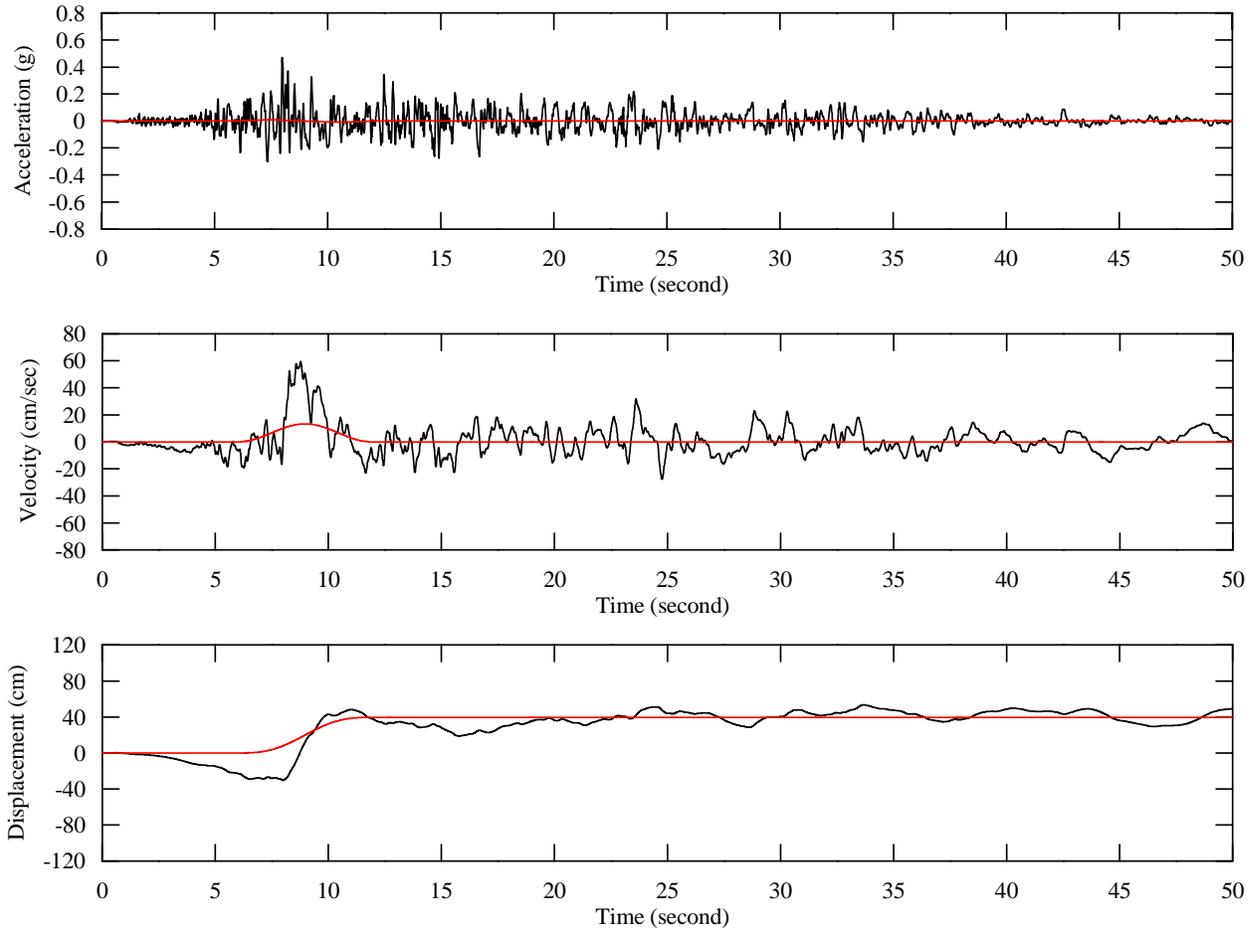


Figure 71: Fault parallel time histories including fling at top of side wall, 1999 Chi-Chi Earthquake

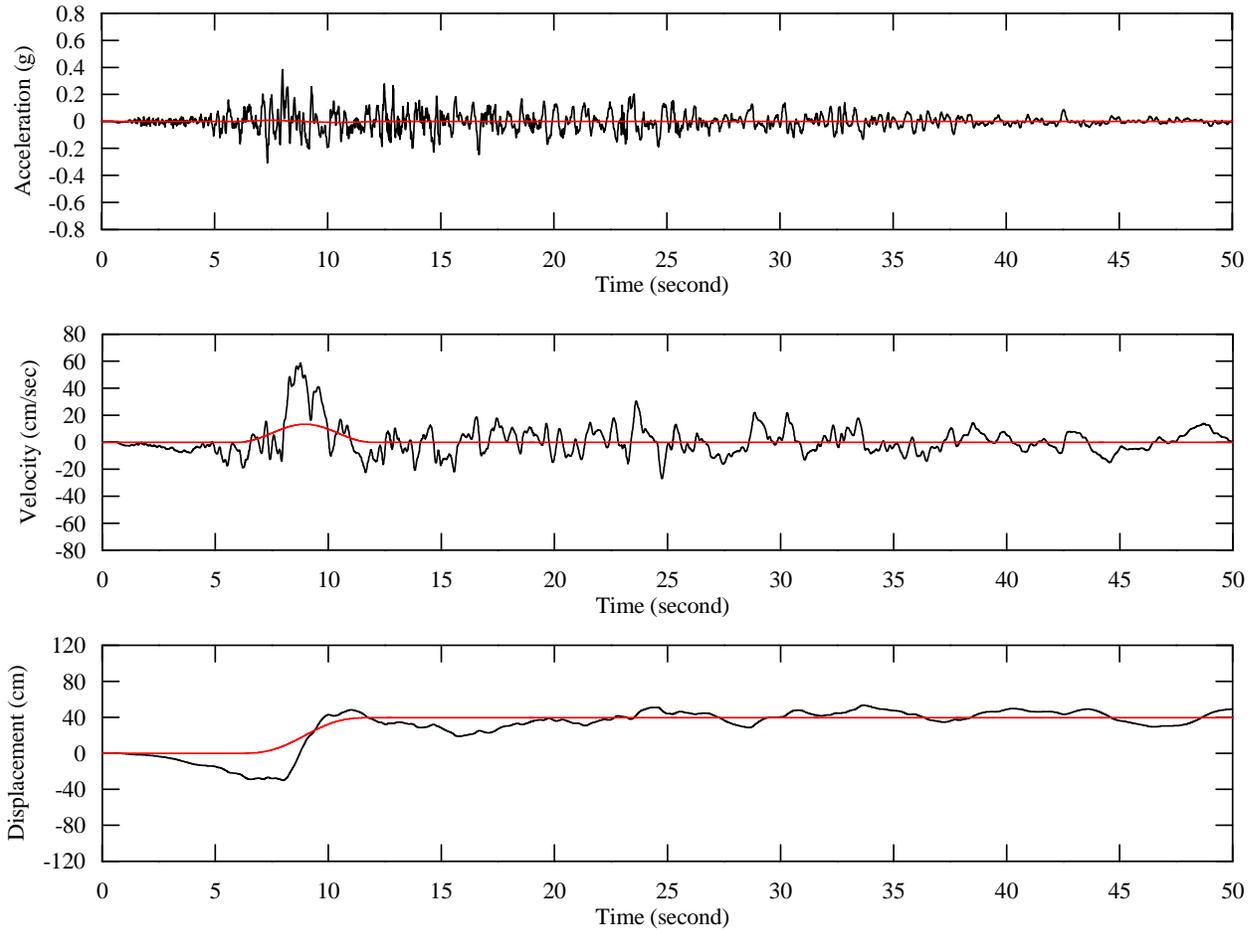


Figure 72: Fault parallel time histories including fling at invert of the tunnel, 1999 Chi-Chi Earthquake

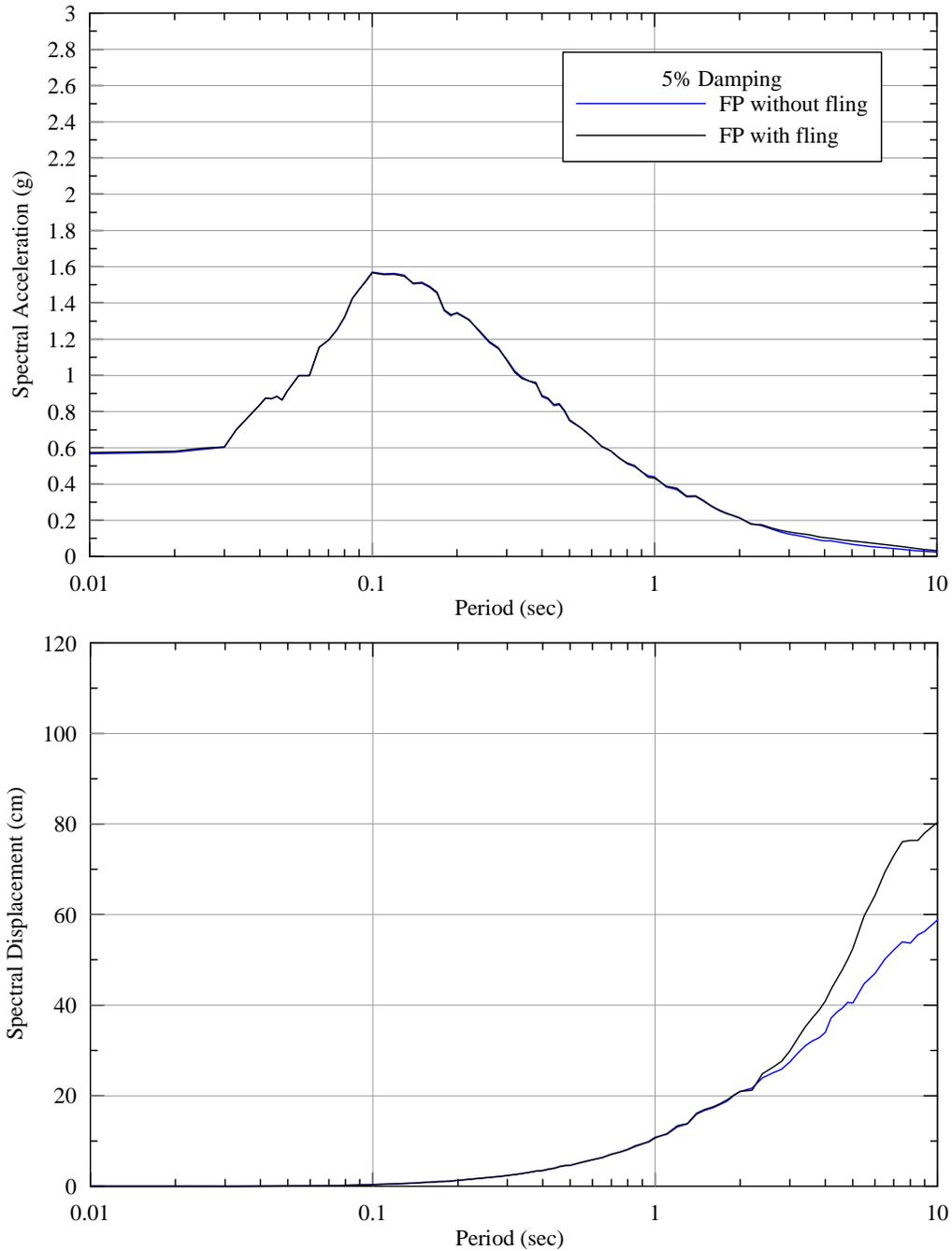


Figure 73: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1999 Chi-Chi Earthquake

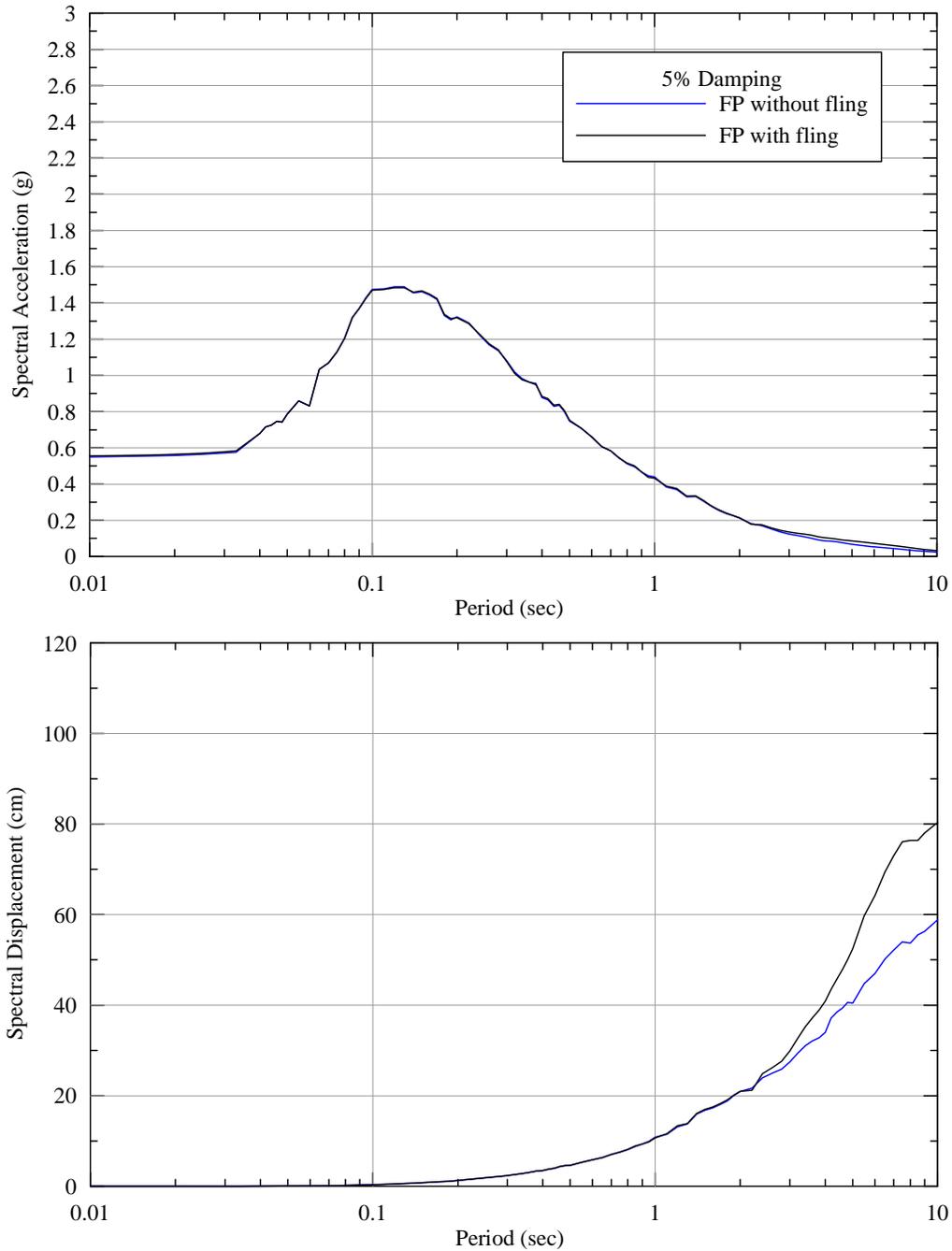


Figure 74: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1999 Chi-Chi Earthquake

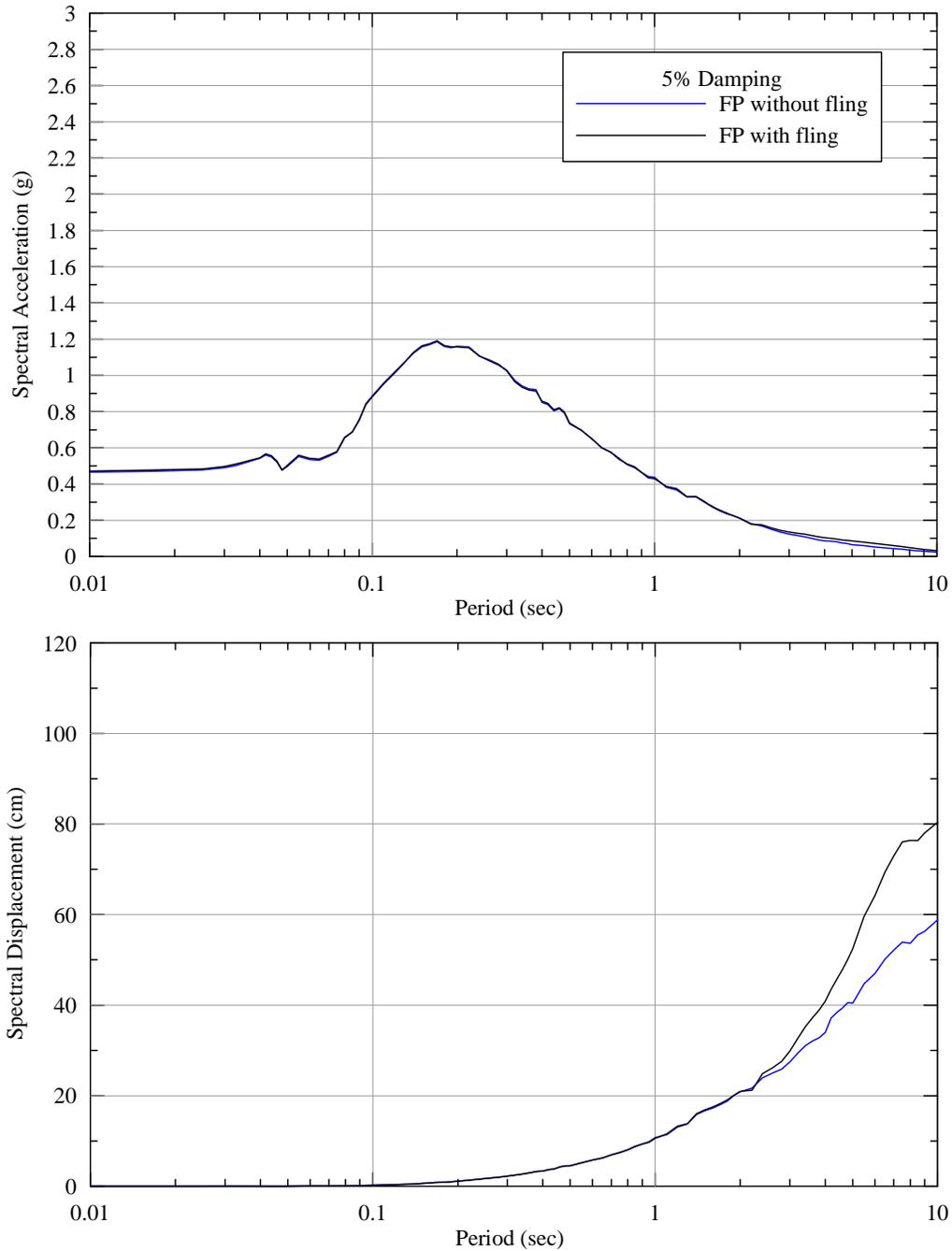


Figure 75: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1999 Chi-Chi Earthquake.

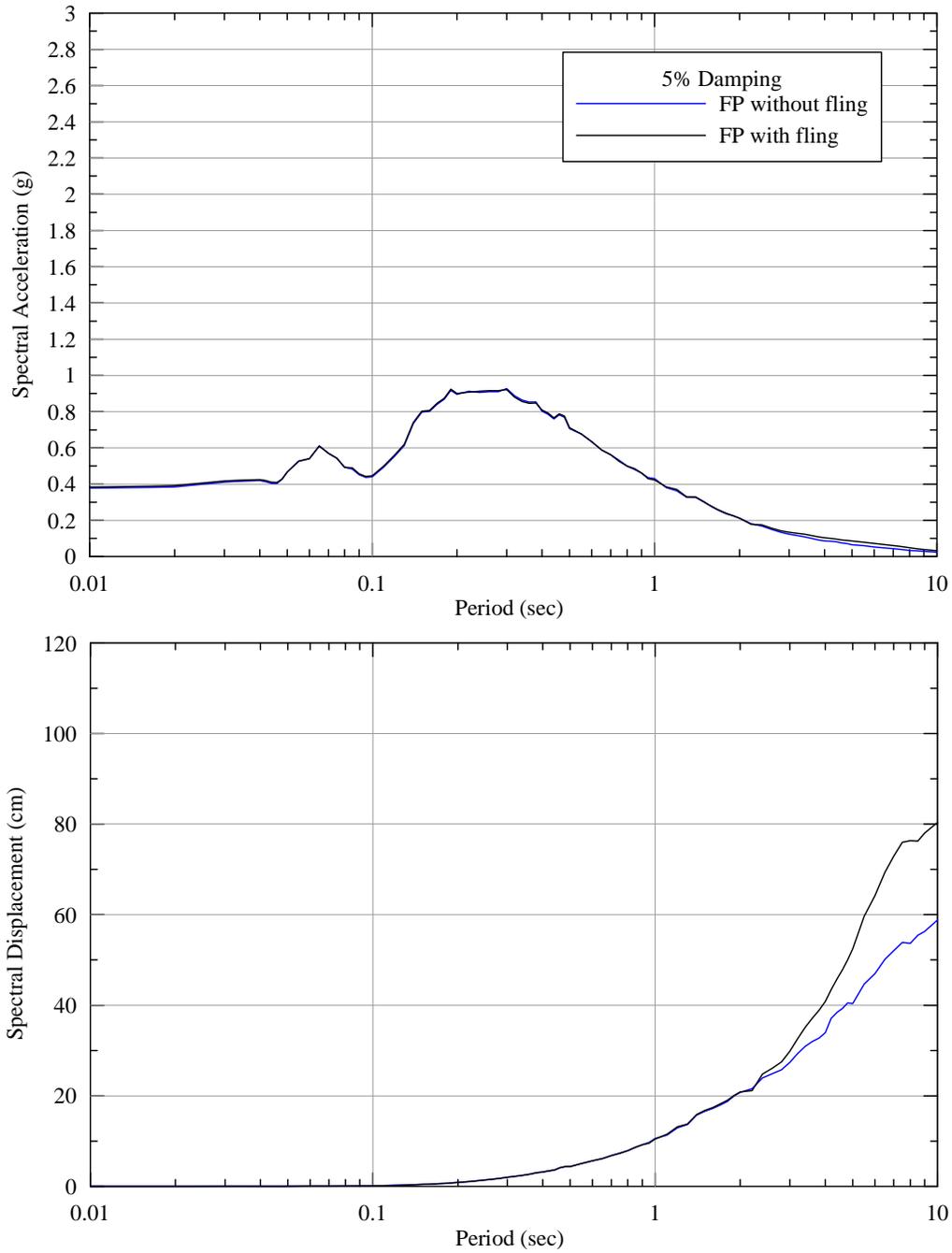


Figure 76: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1999 Chi-Chi Earthquake

BTSB-R3 PROFILE (BATTERY TUNNEL)

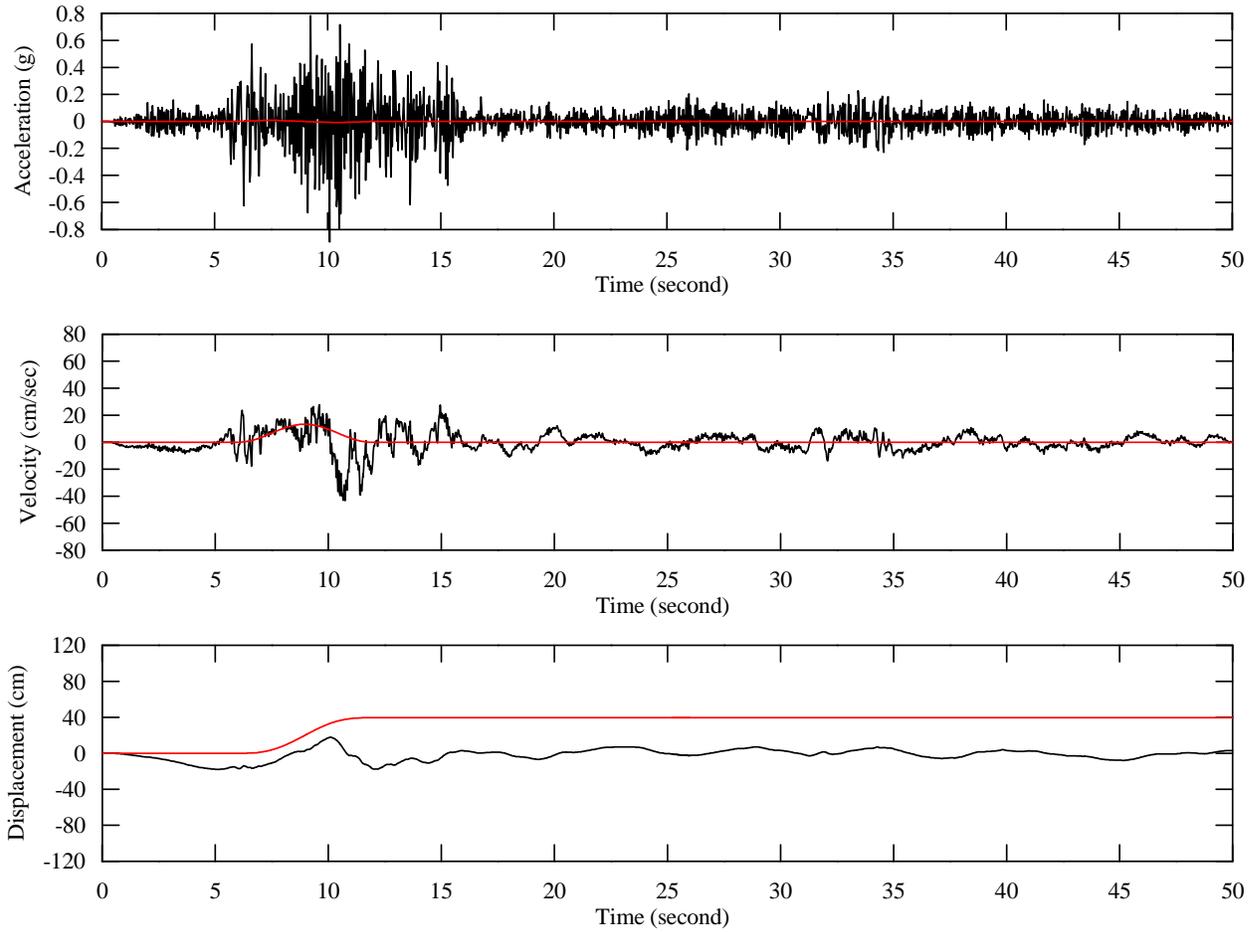


Figure 77: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1990 Manjil Earthquake

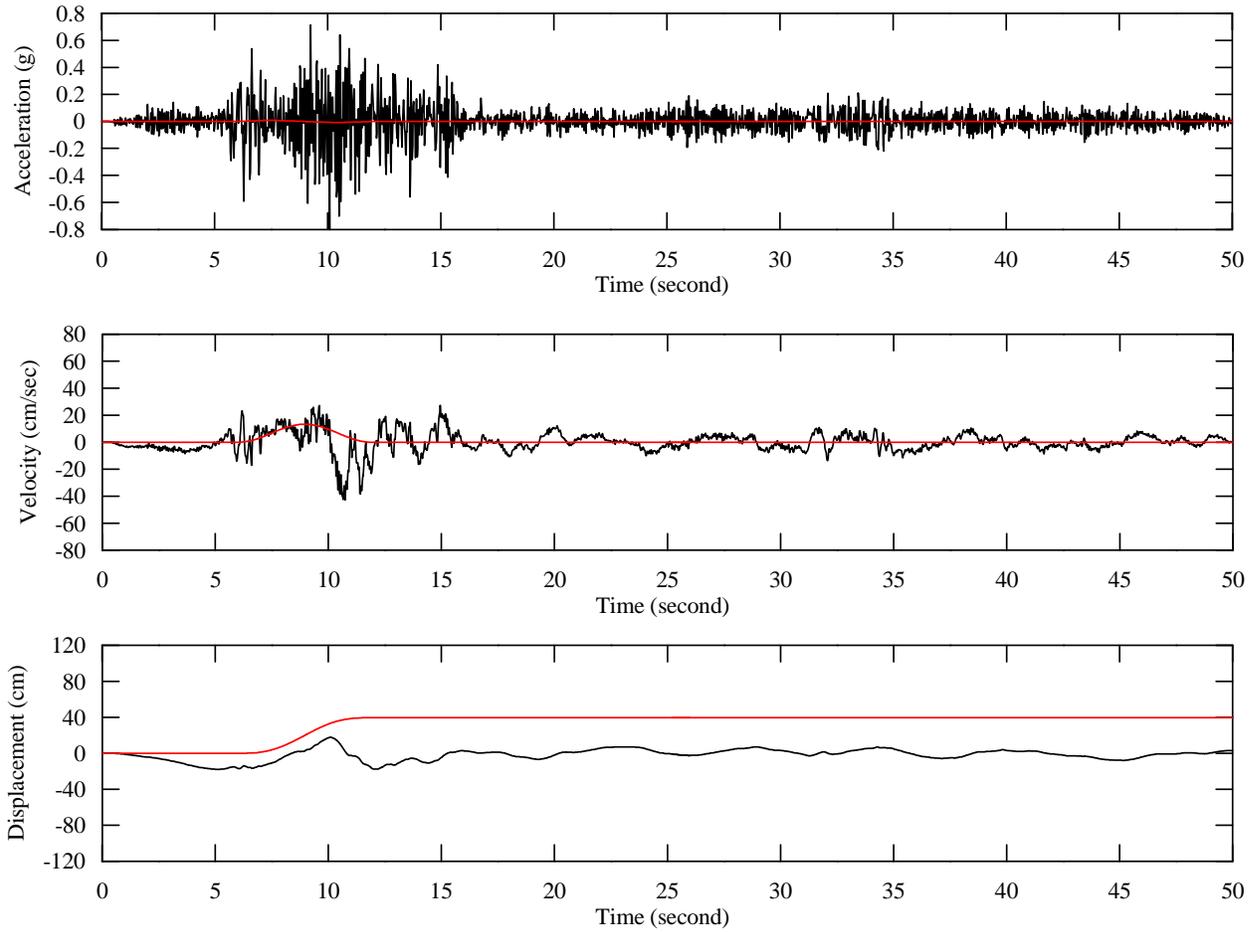


Figure 78: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1990 Manjil Earthquake

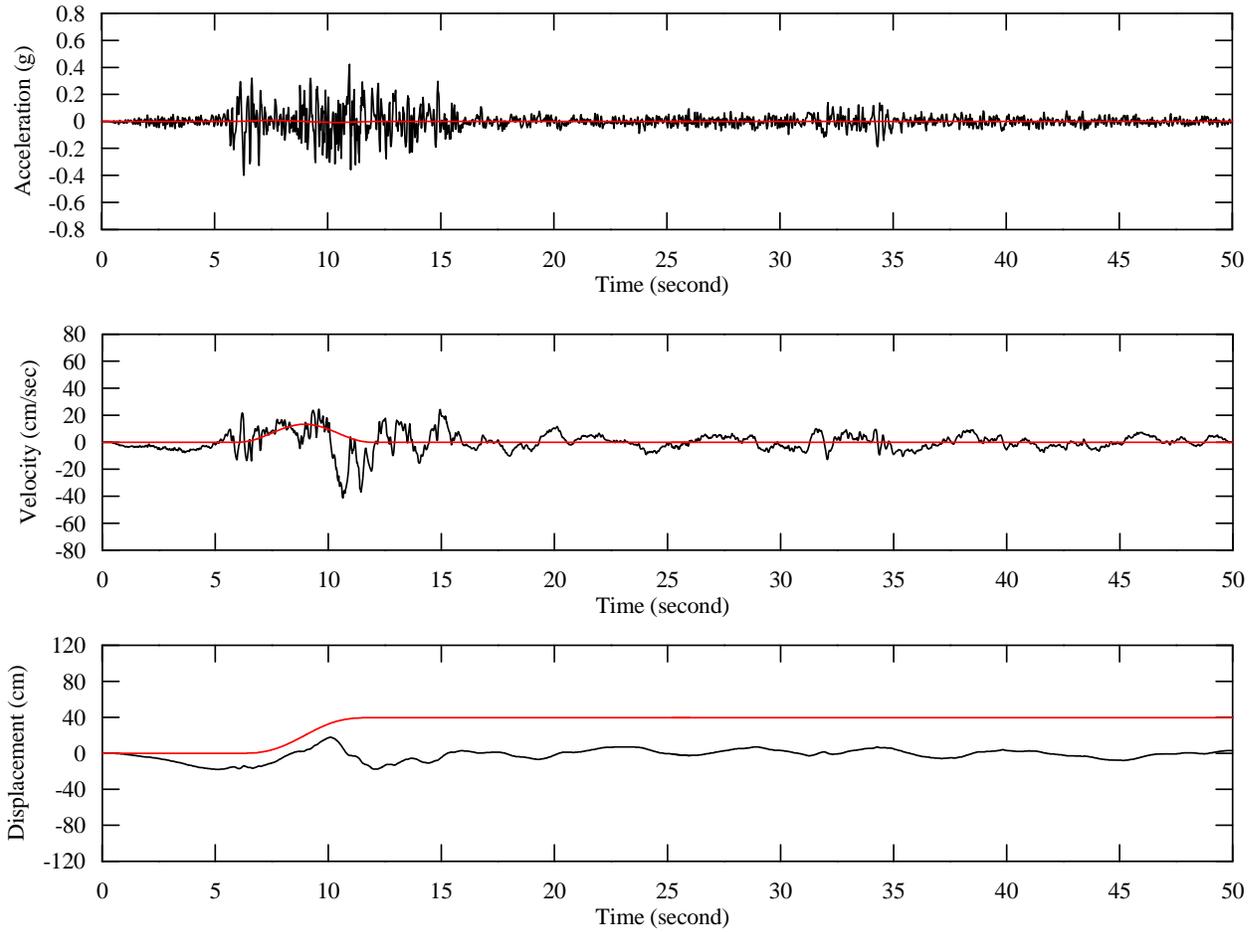


Figure 79: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1990 Manjil Earthquake

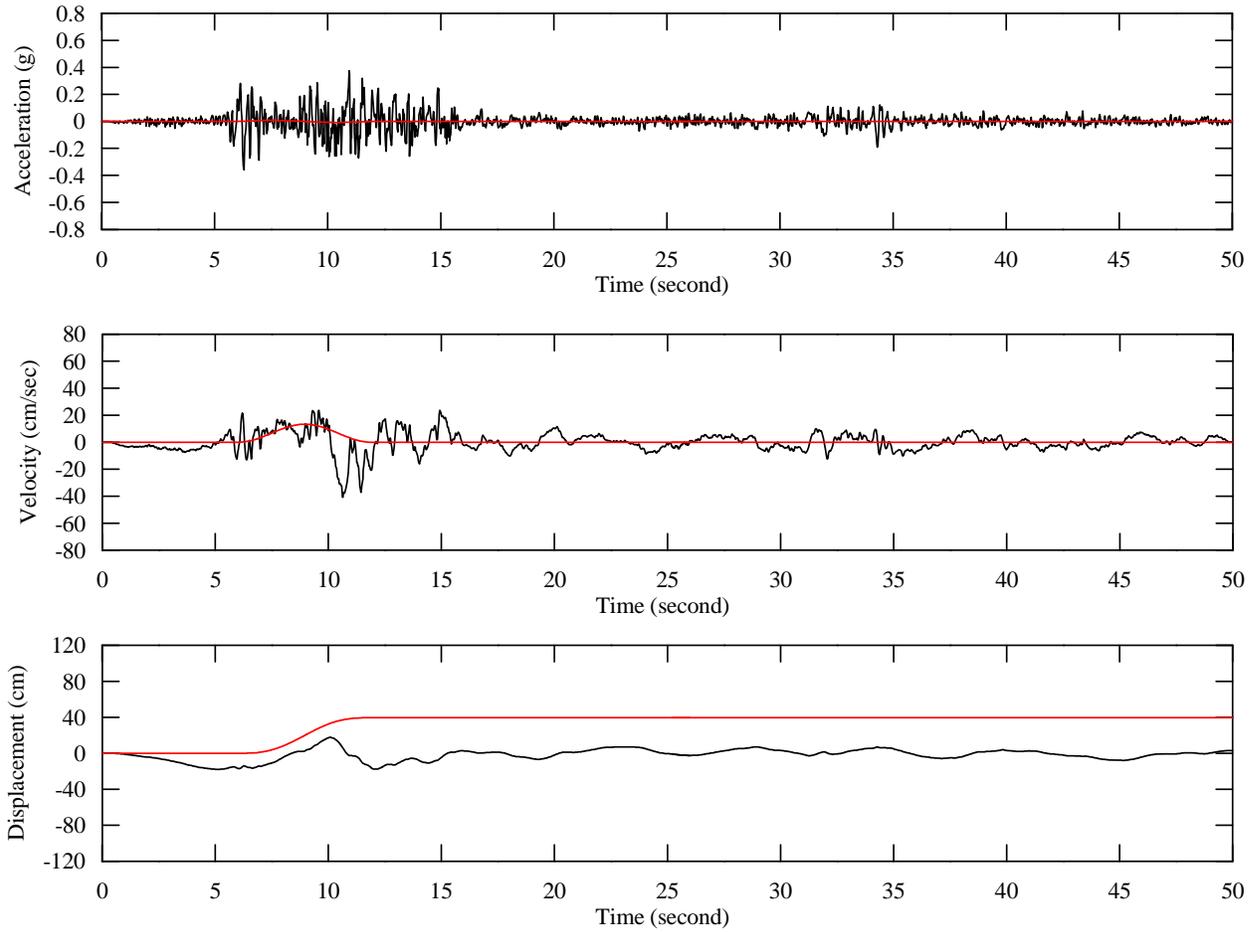


Figure 80: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1990 Manjil Earthquake

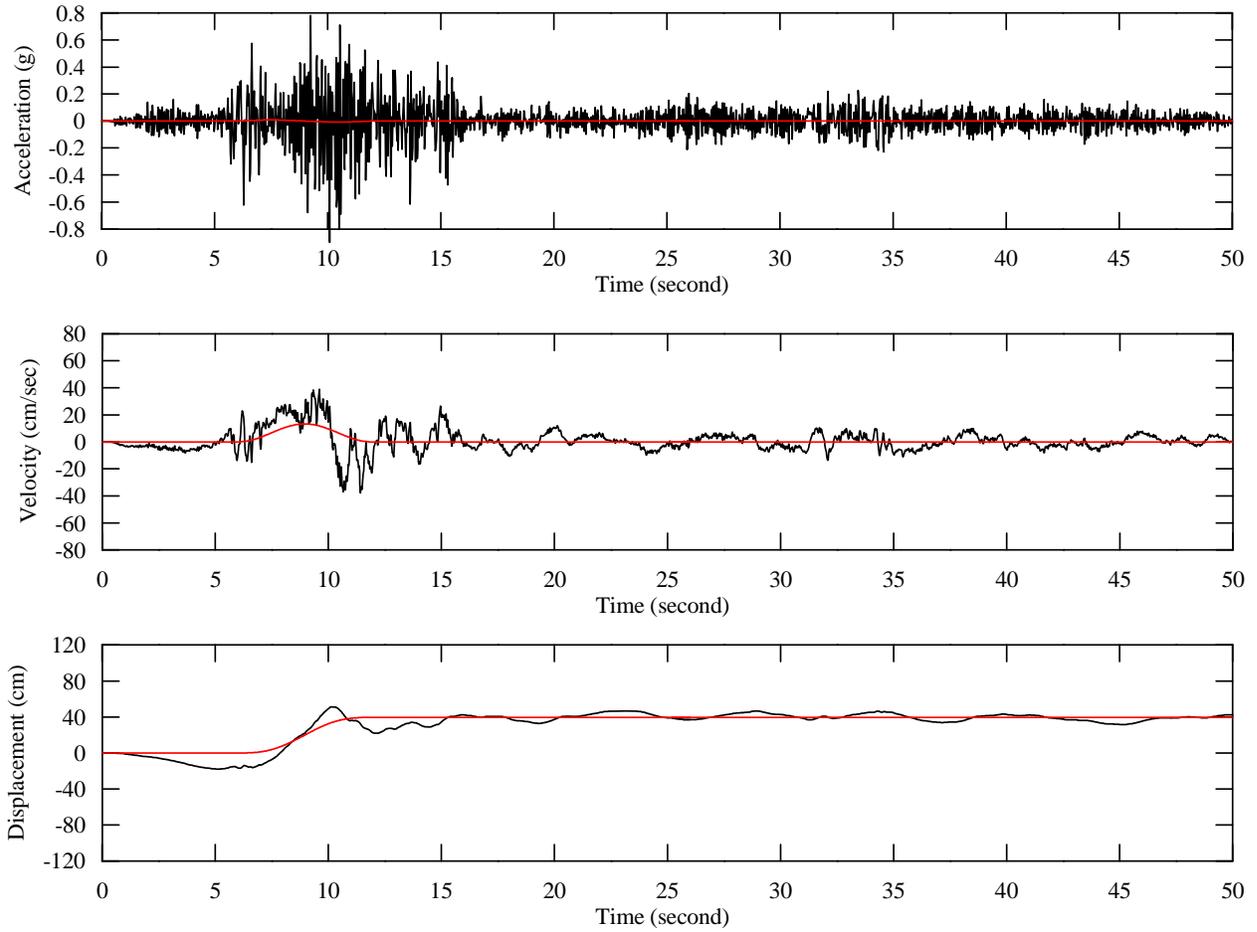


Figure 81: Fault parallel time histories including fling at ground surface, 1990 Manjil Earthquake

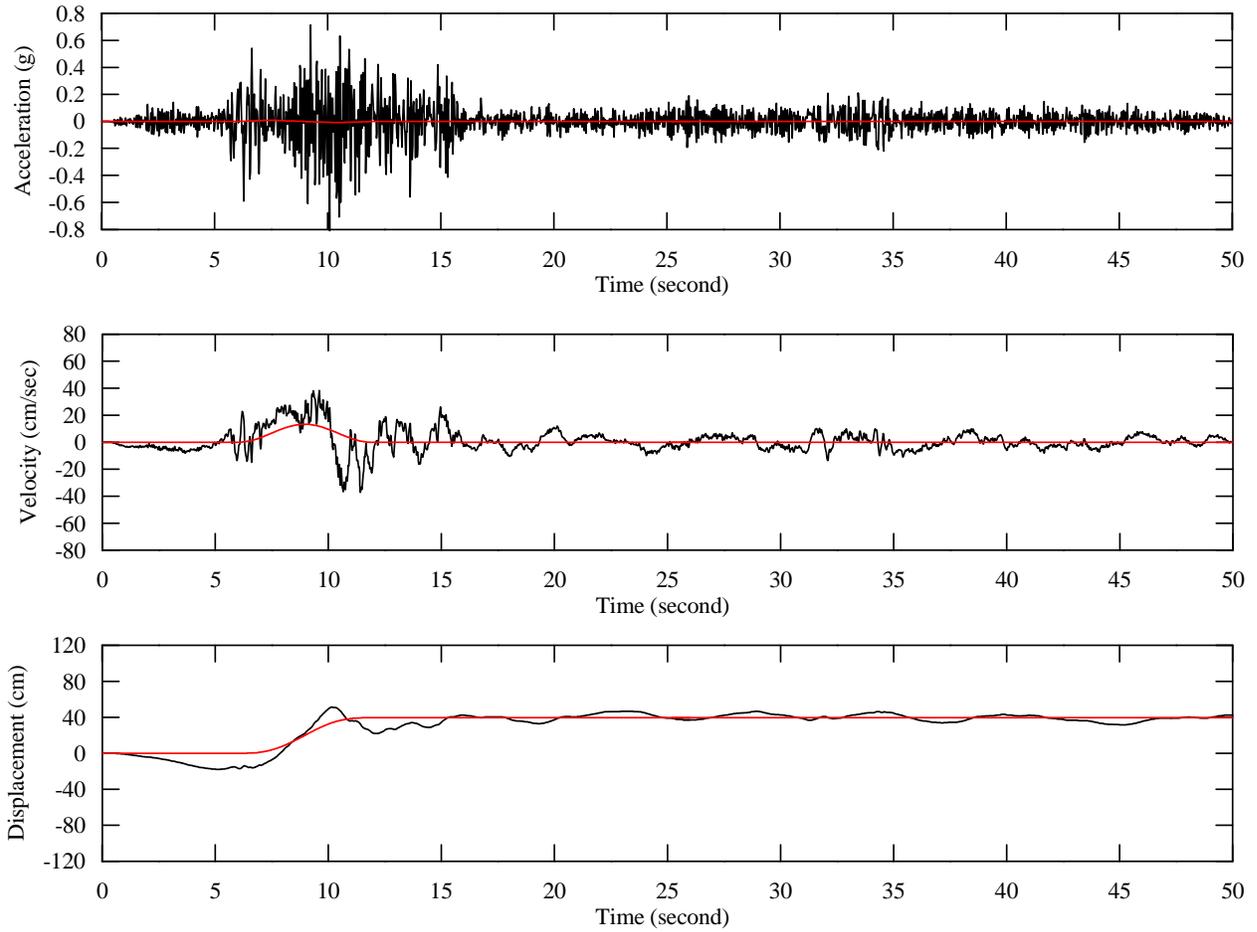


Figure 82: Fault parallel time histories including fling at crown of the tunnel, 1990 Manjil Earthquake

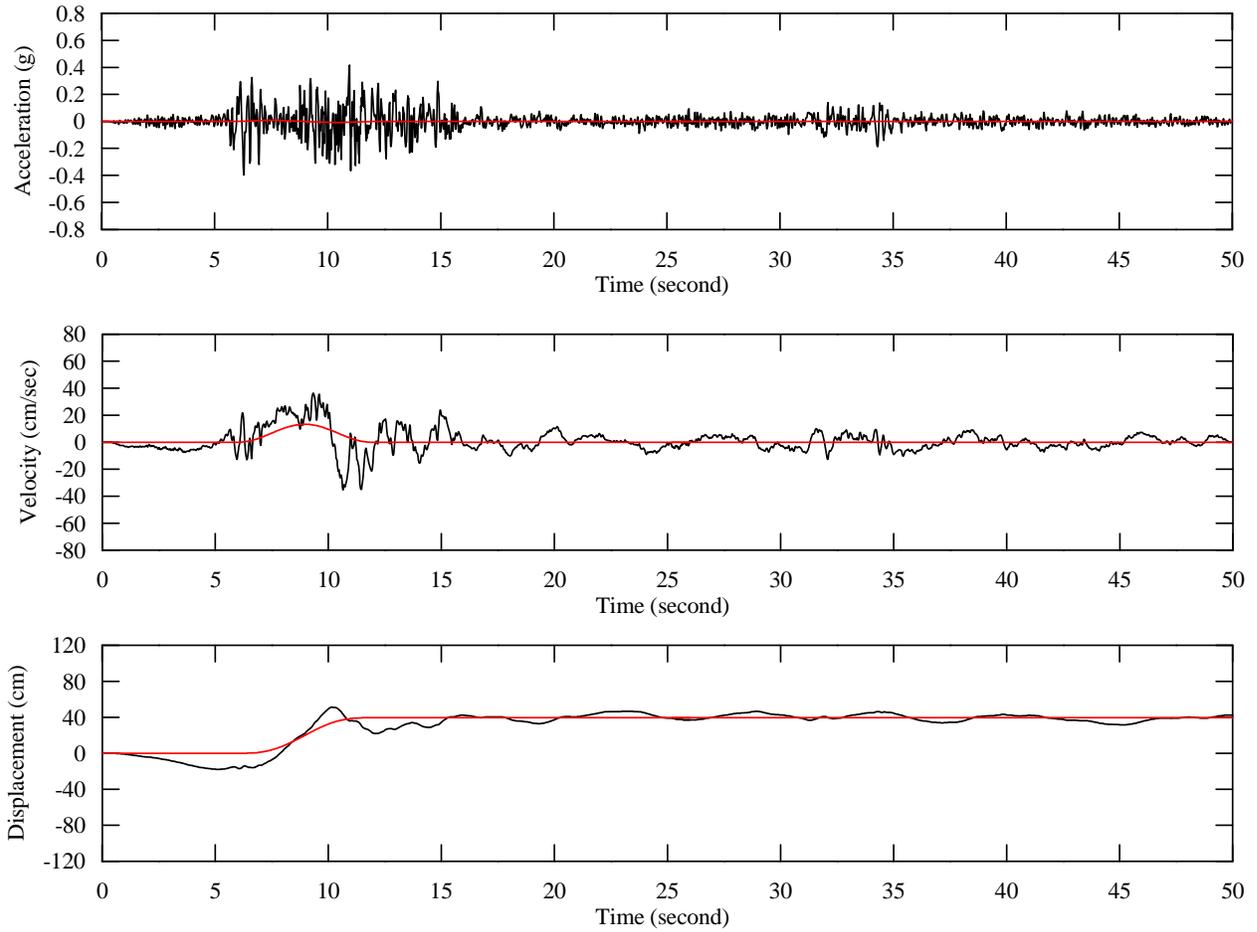


Figure 83: Fault parallel time histories including fling at top of side wall, 1990 Manjil Earthquake

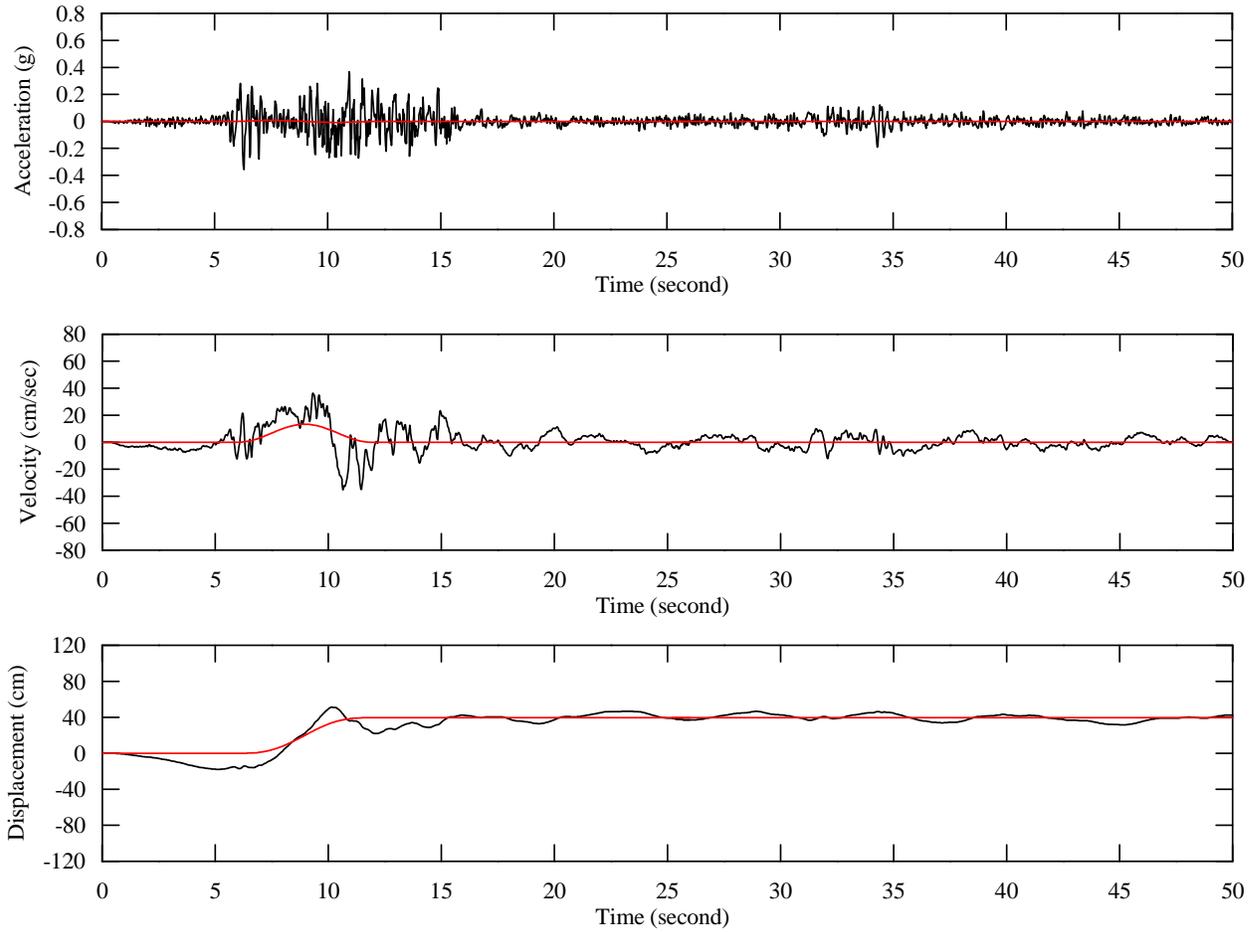


Figure 84: Fault parallel time histories including fling at invert of the tunnel, 1990 Manjil Earthquake

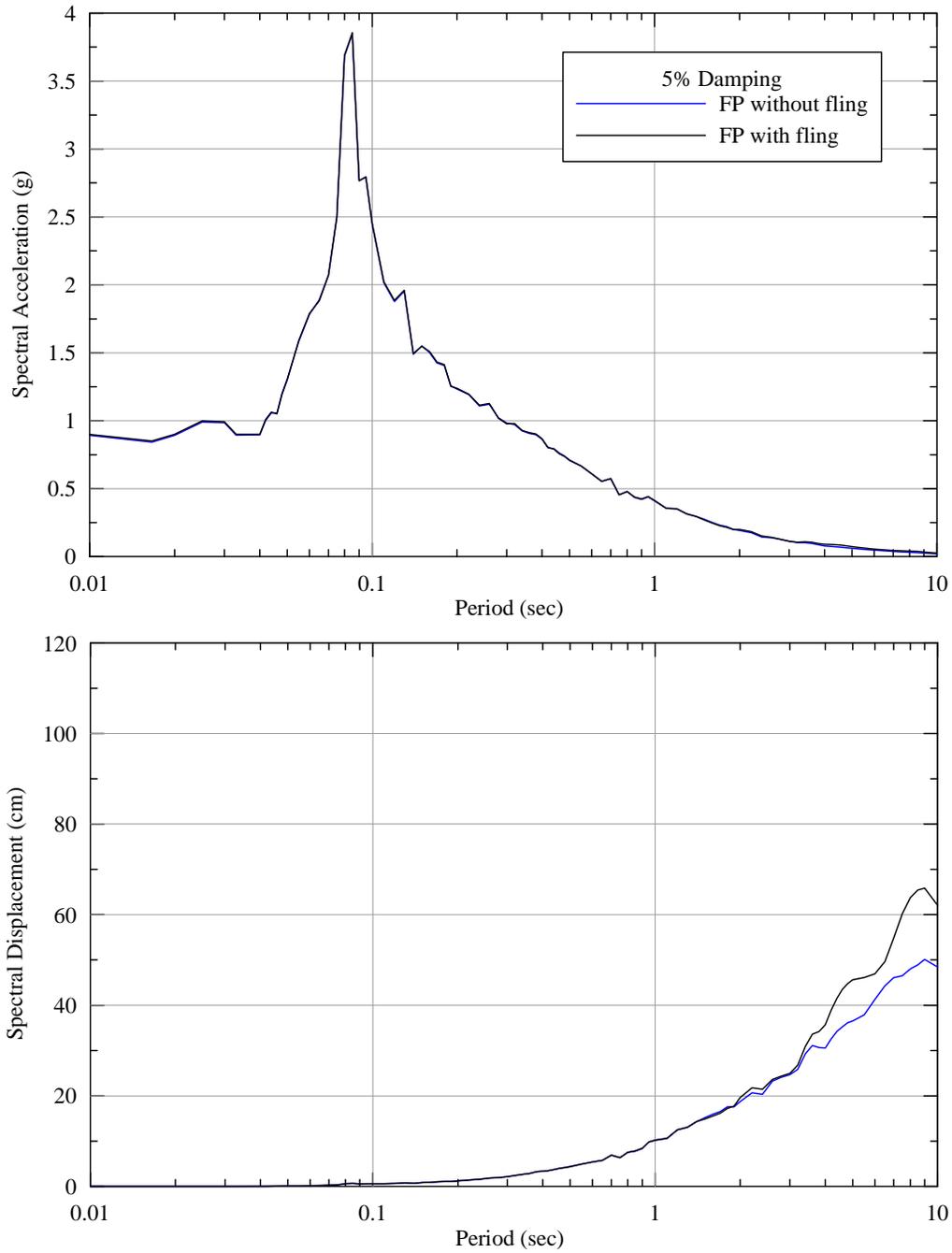


Figure 85: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1990 Manjil Earthquake

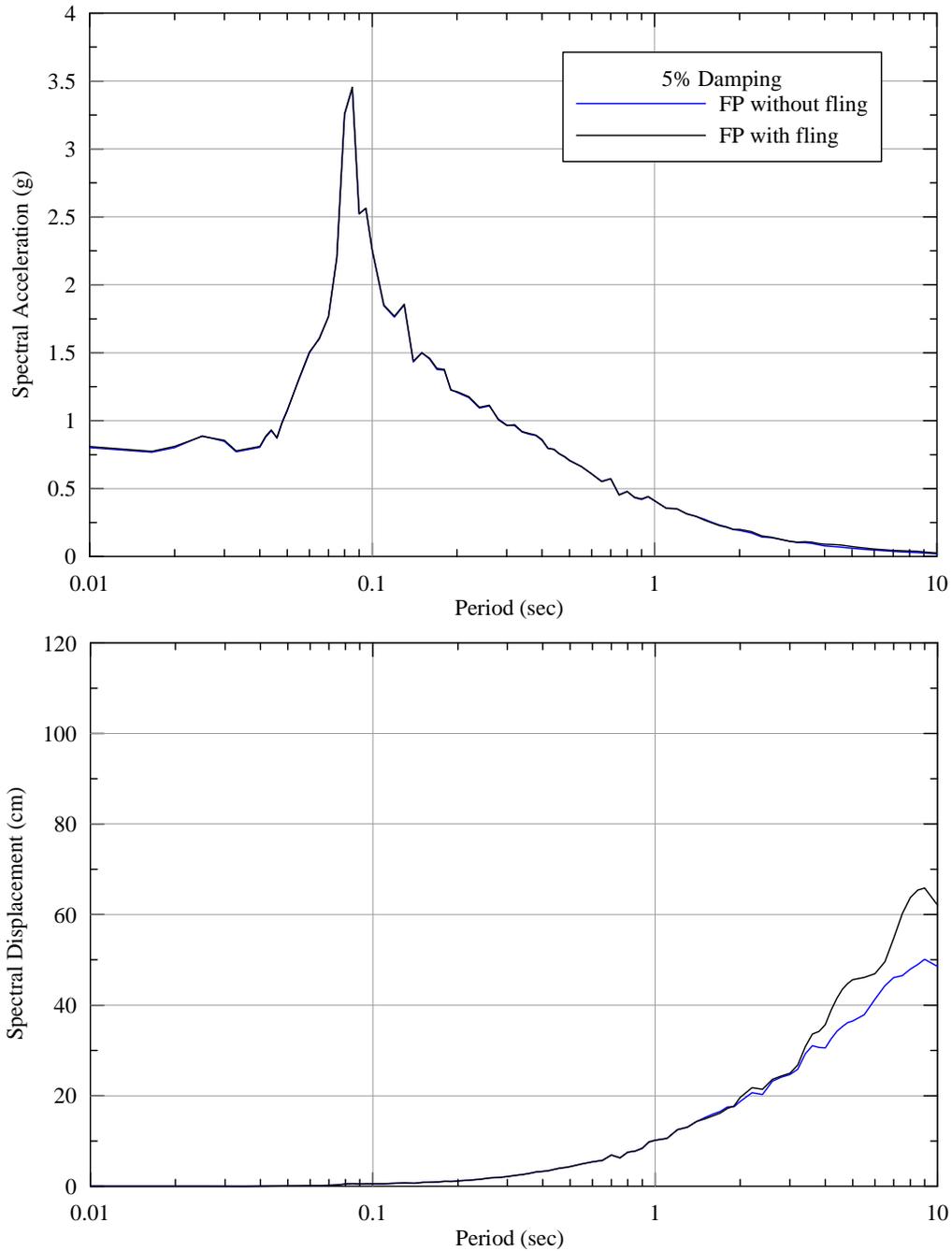


Figure 86: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1990 Manjil Earthquake

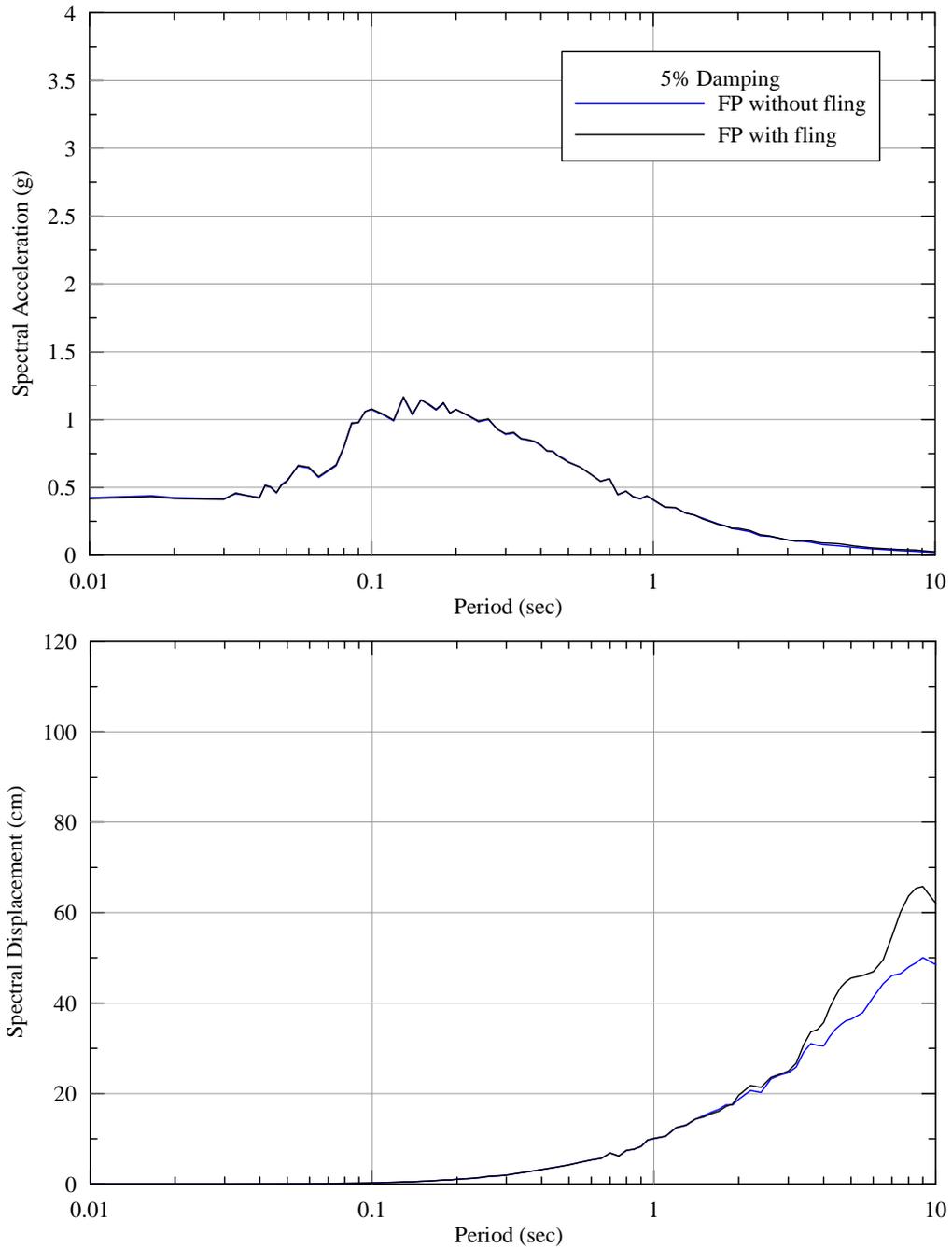


Figure 87: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1990 Manjil Earthquake

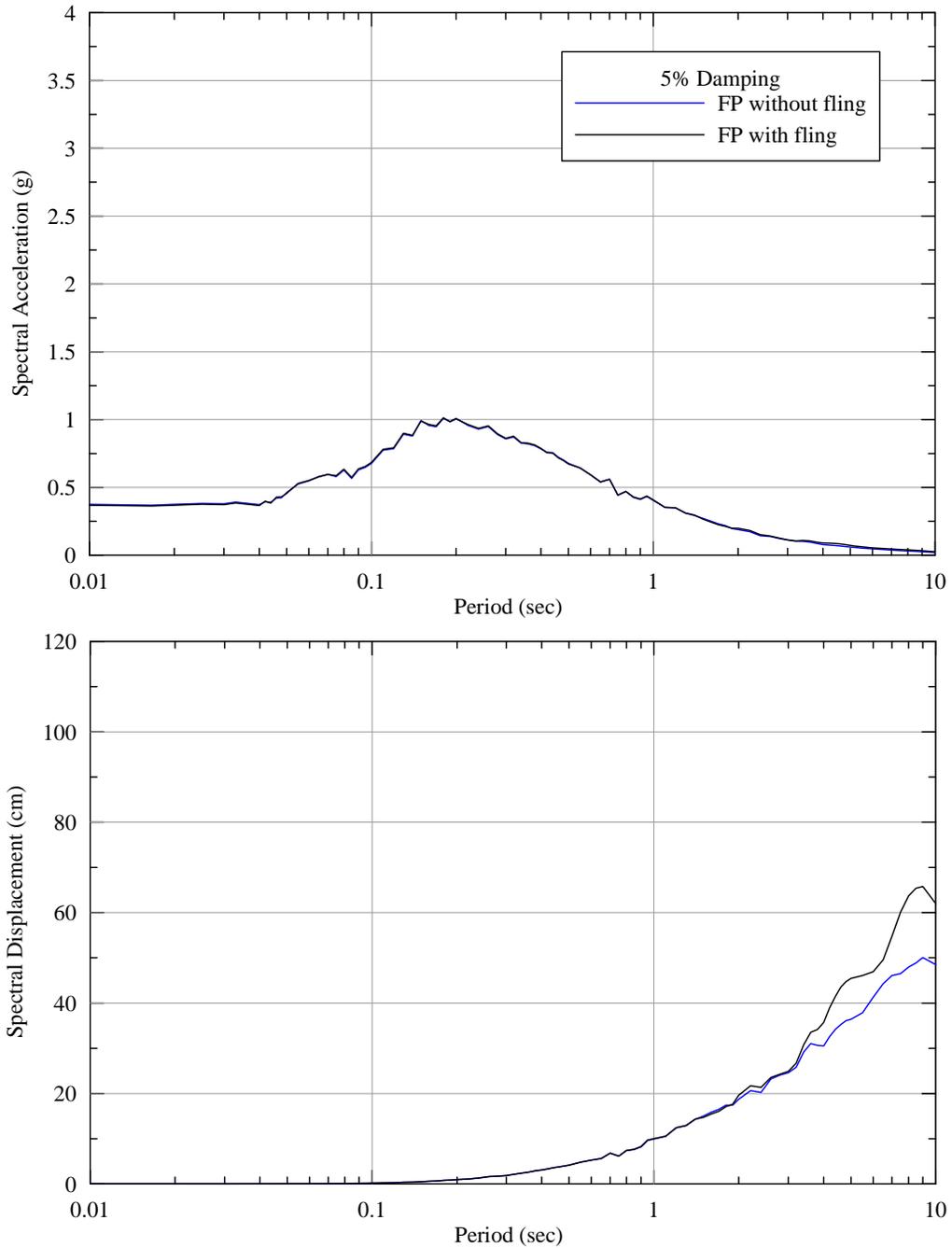


Figure 88: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1990 Manjil Earthquake

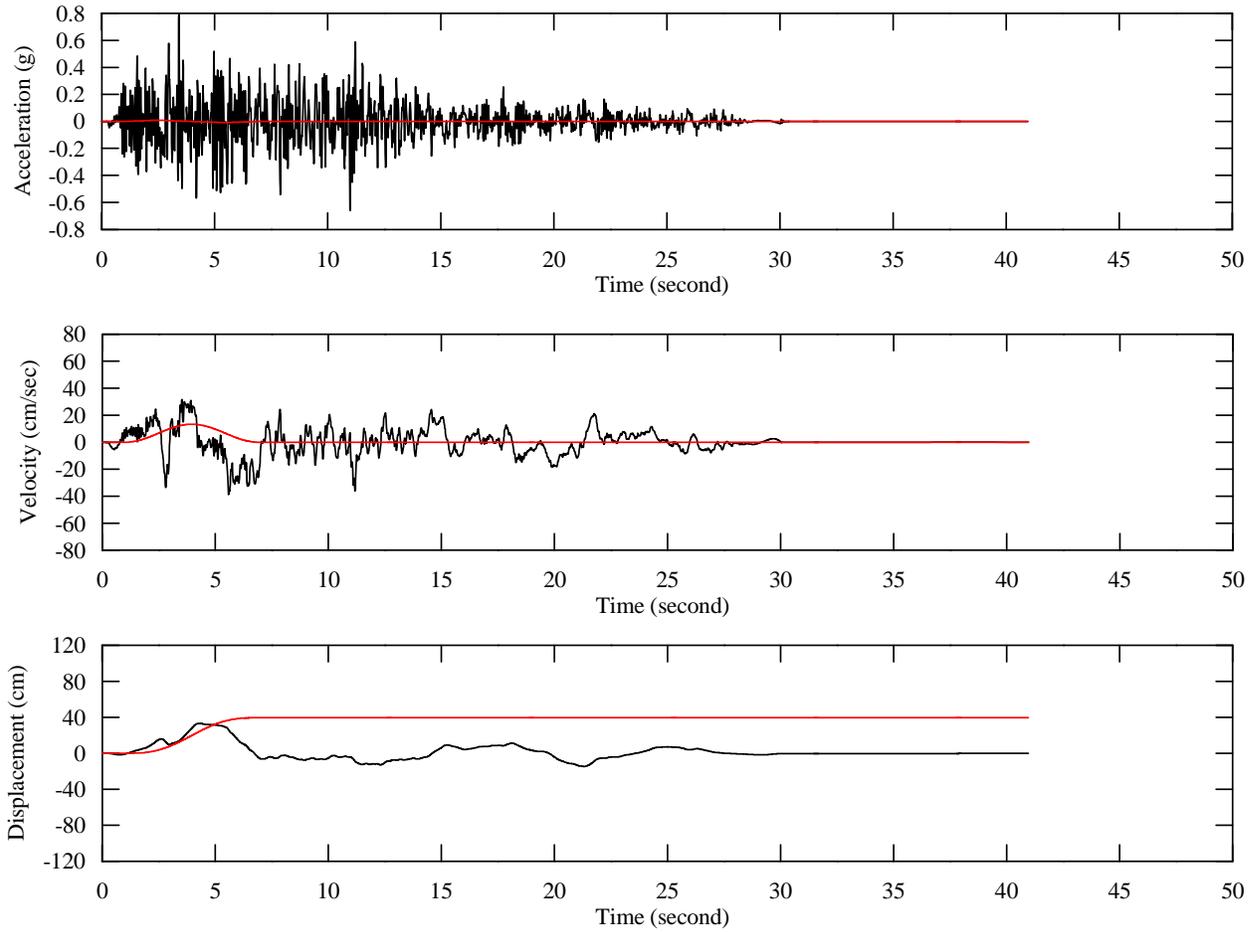


Figure 89: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1999 Kocaeli Earthquake

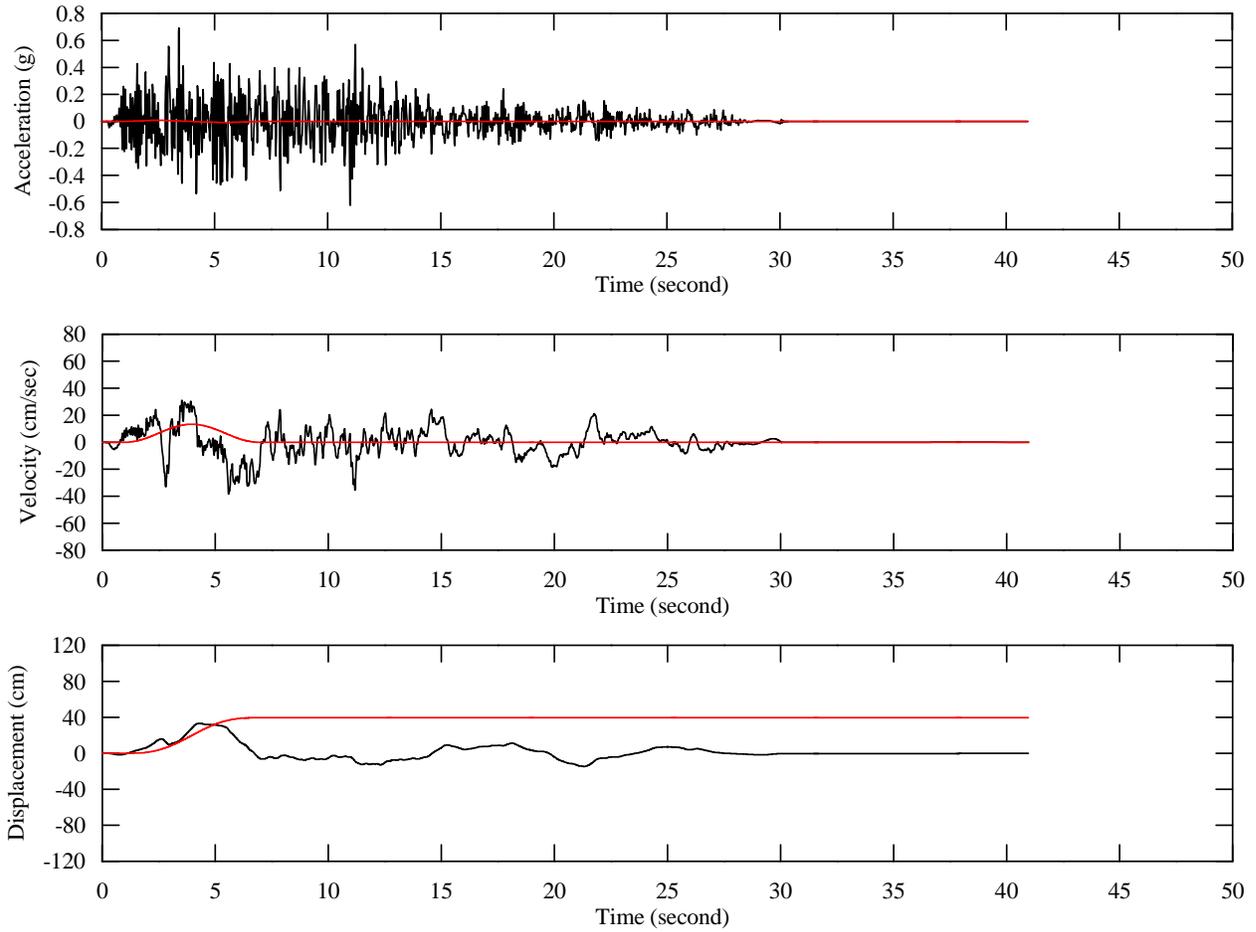


Figure 90: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1999 Kocaeli Earthquake

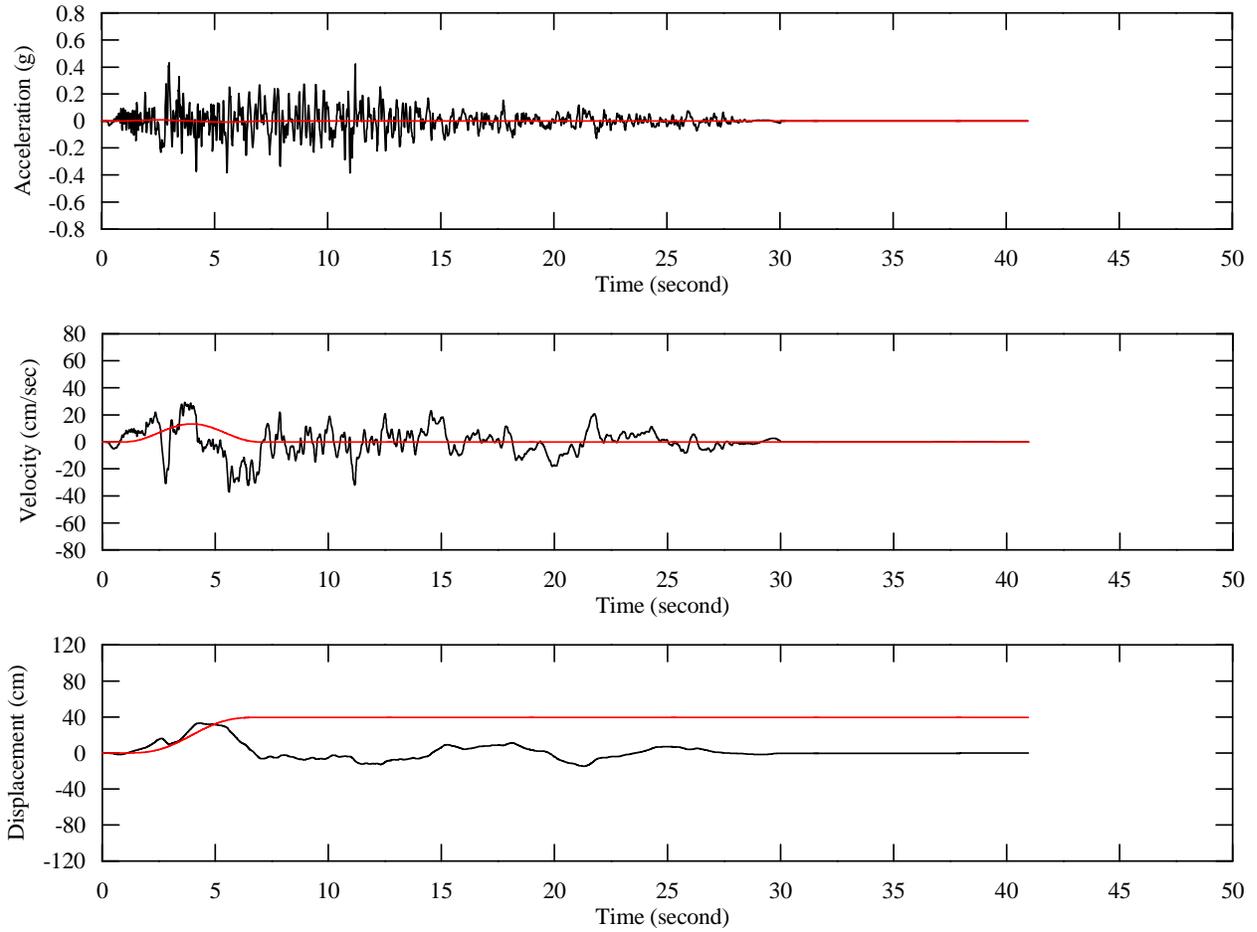


Figure 91: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1999 Kocaeli Earthquake

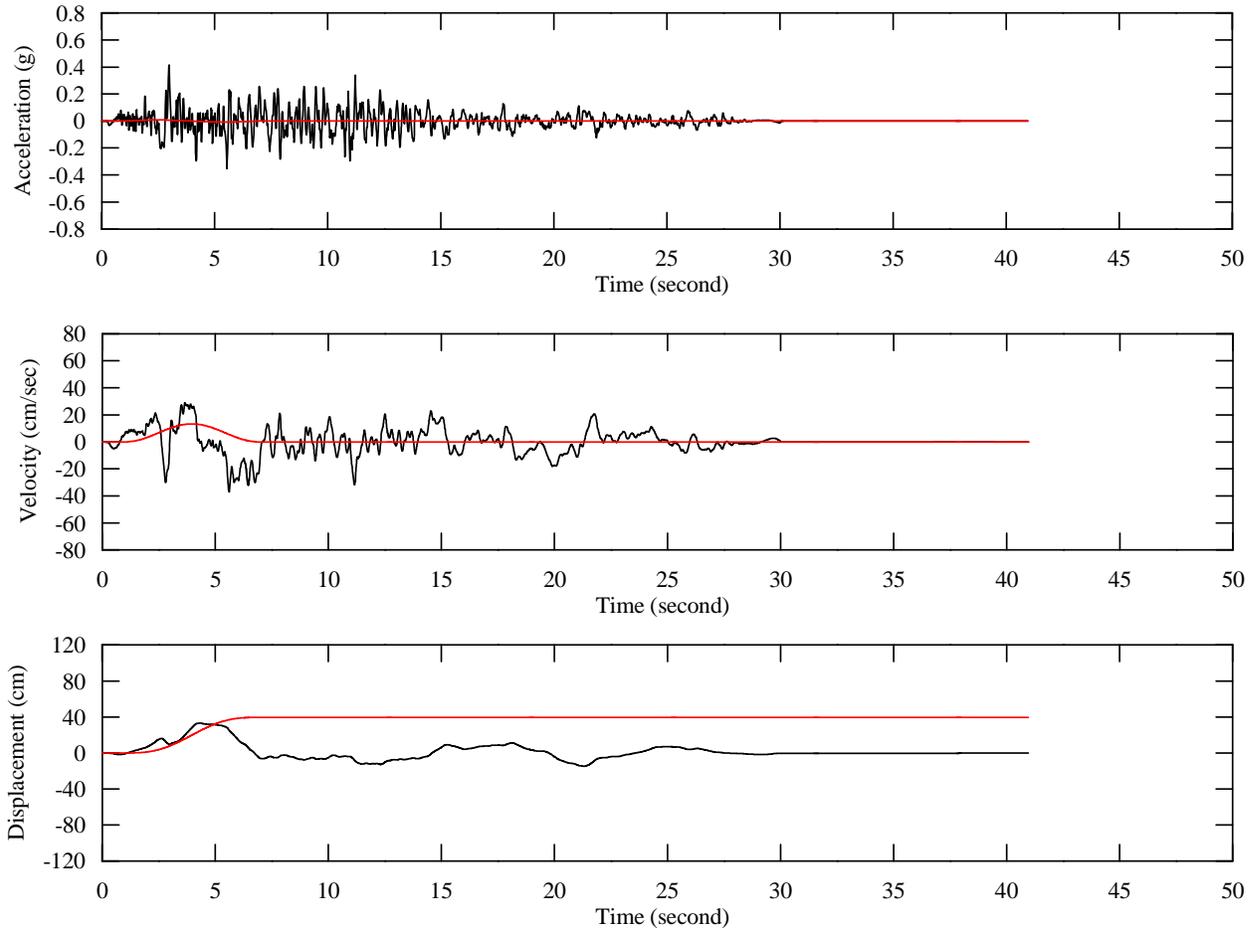


Figure 92: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1999 Kocaeli Earthquake

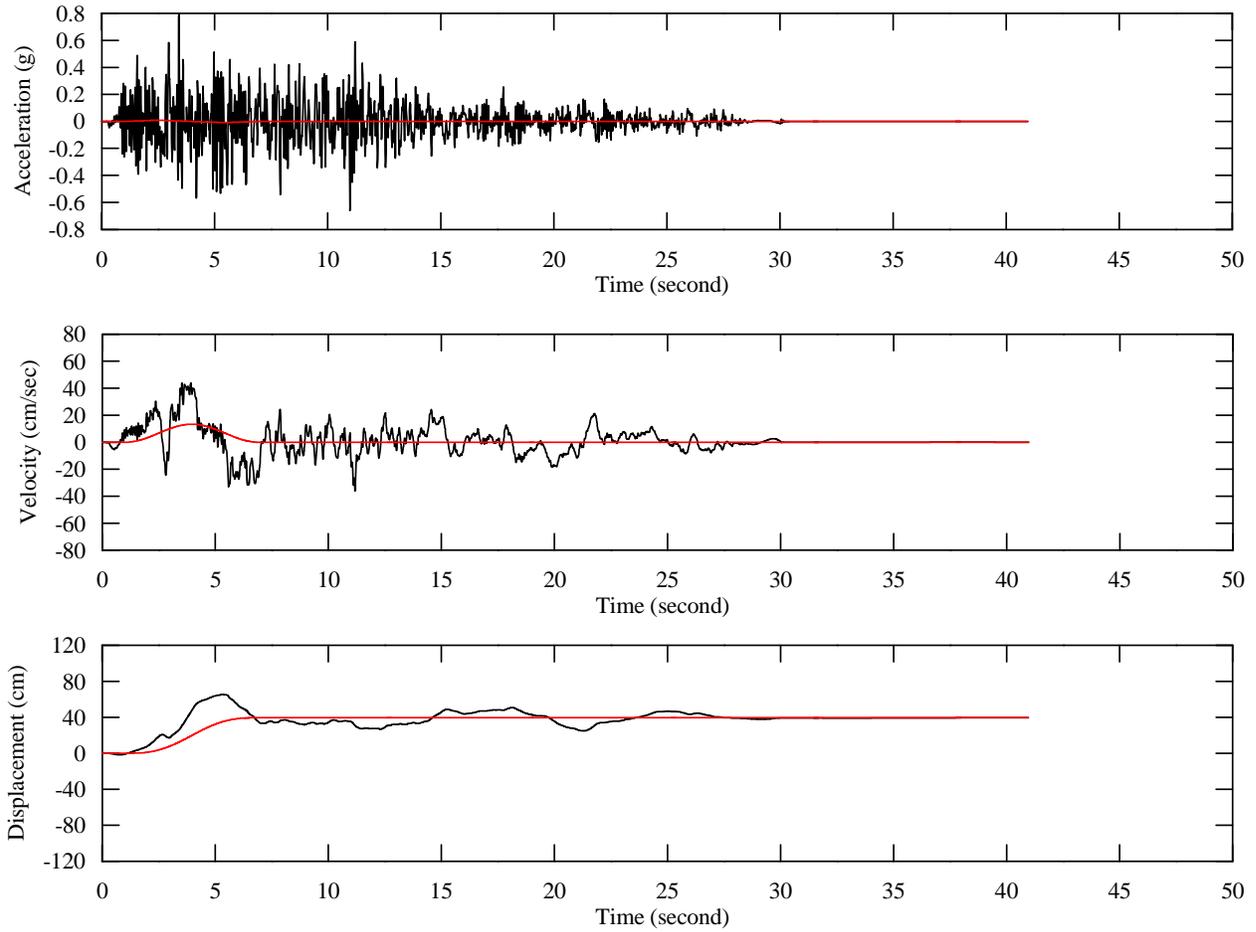


Figure 93: Fault parallel time histories including fling at ground surface, 1999 Kocaeli Earthquake

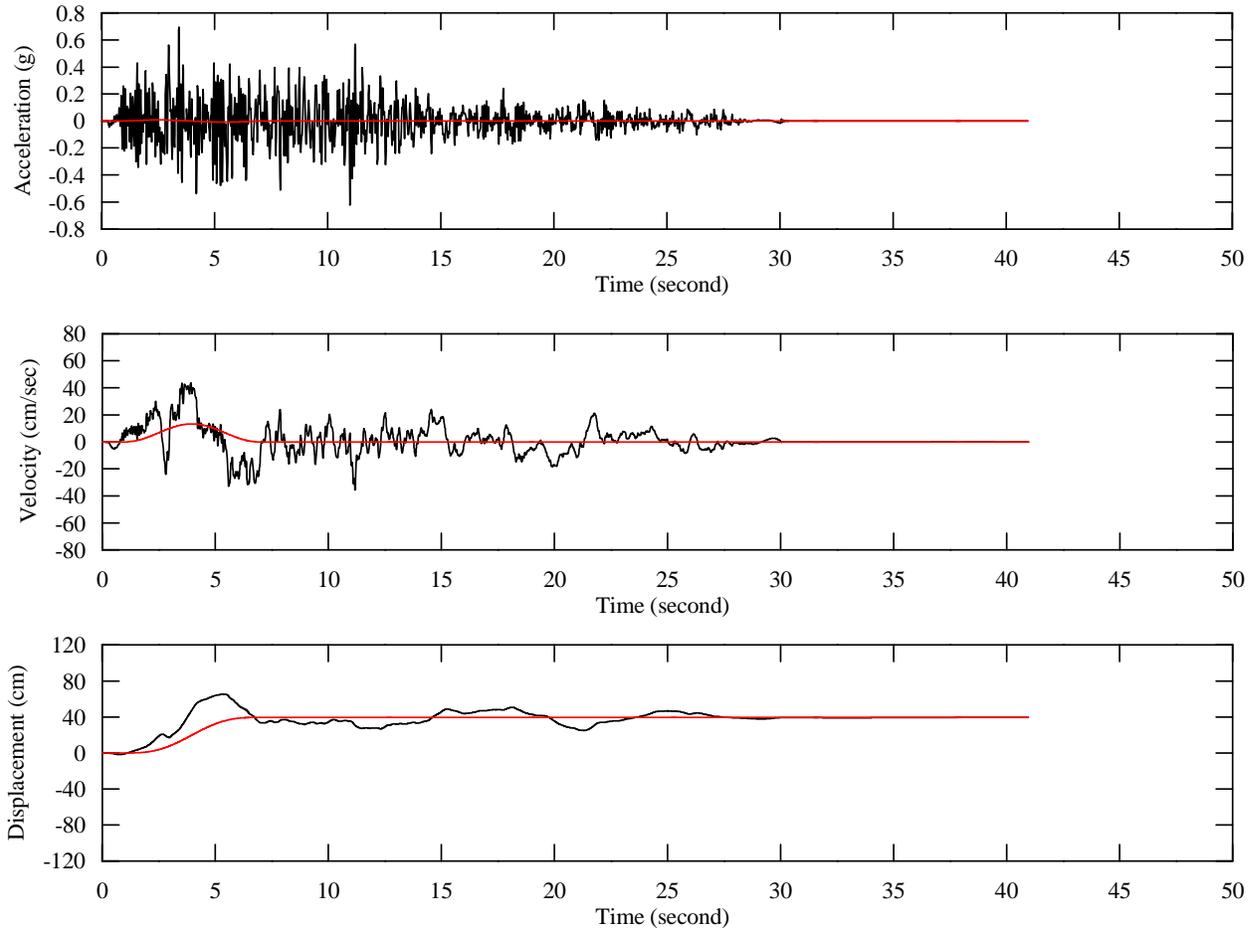


Figure 94: Fault parallel time histories including fling at crown of the tunnel, 1999 Kocaeli Earthquake

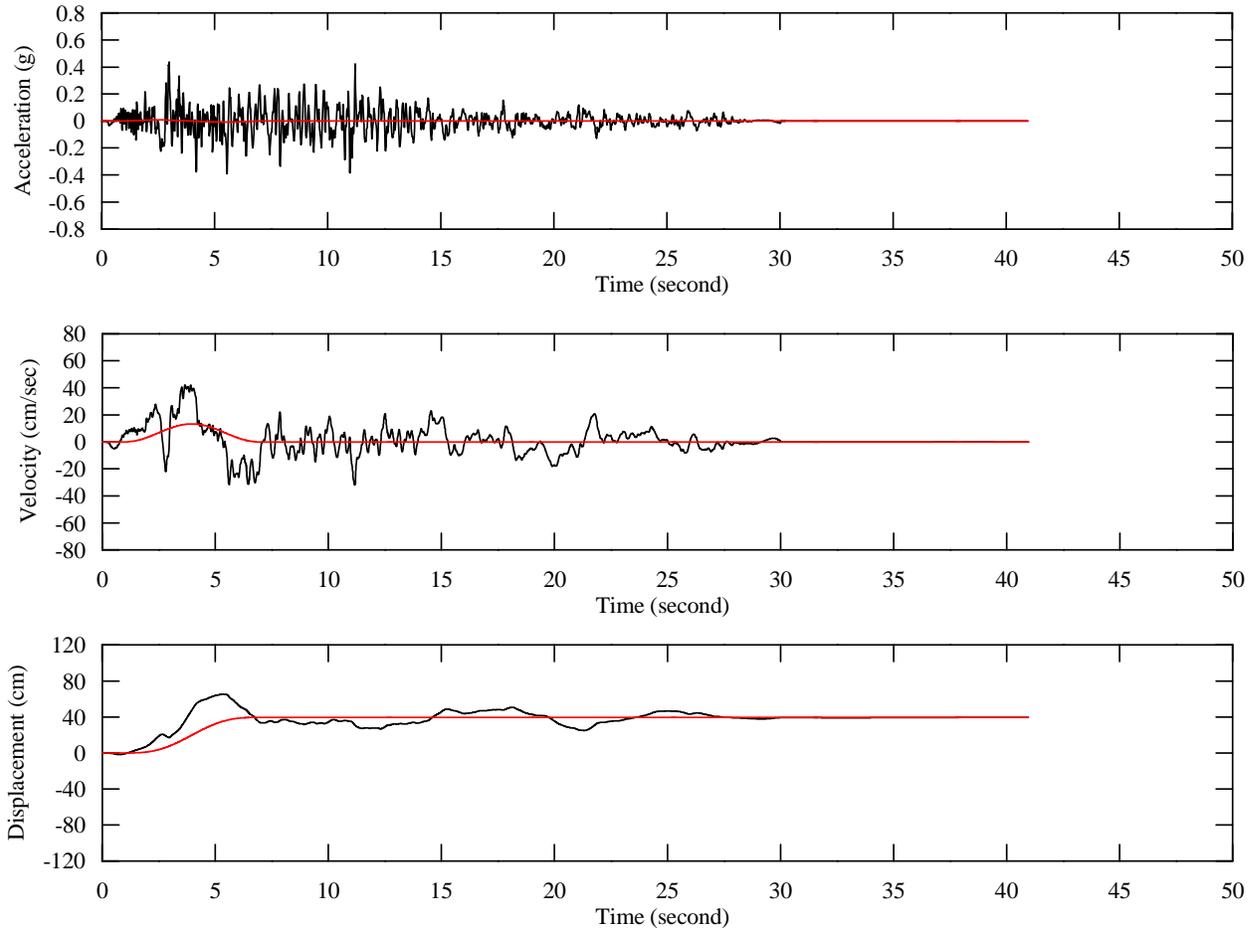


Figure 95: Fault parallel time histories including fling at top of side wall, 1999 Kocaeli Earthquake

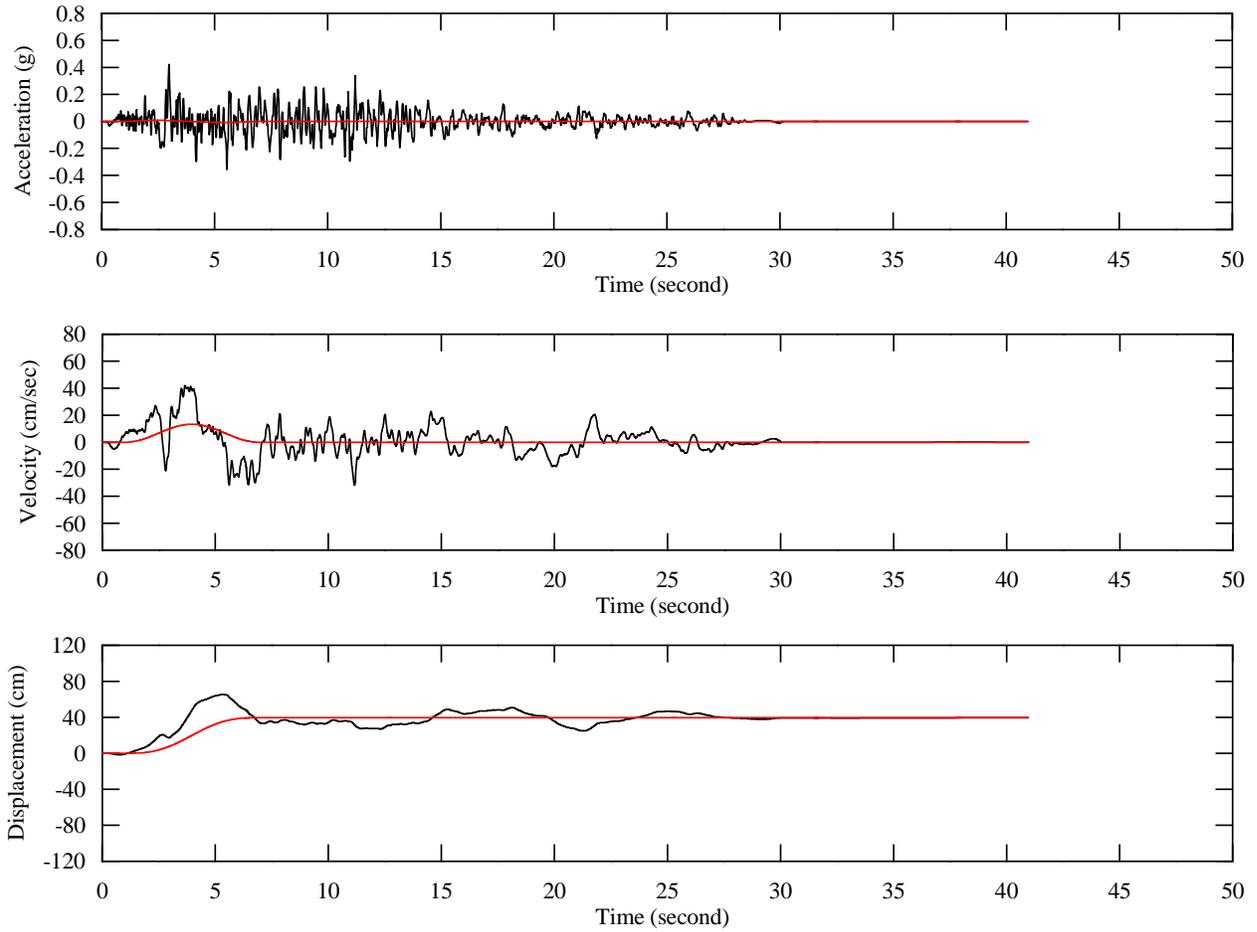


Figure 96: Fault parallel time histories including fling at invert of the tunnel, 1999 Kocaeli Earthquake

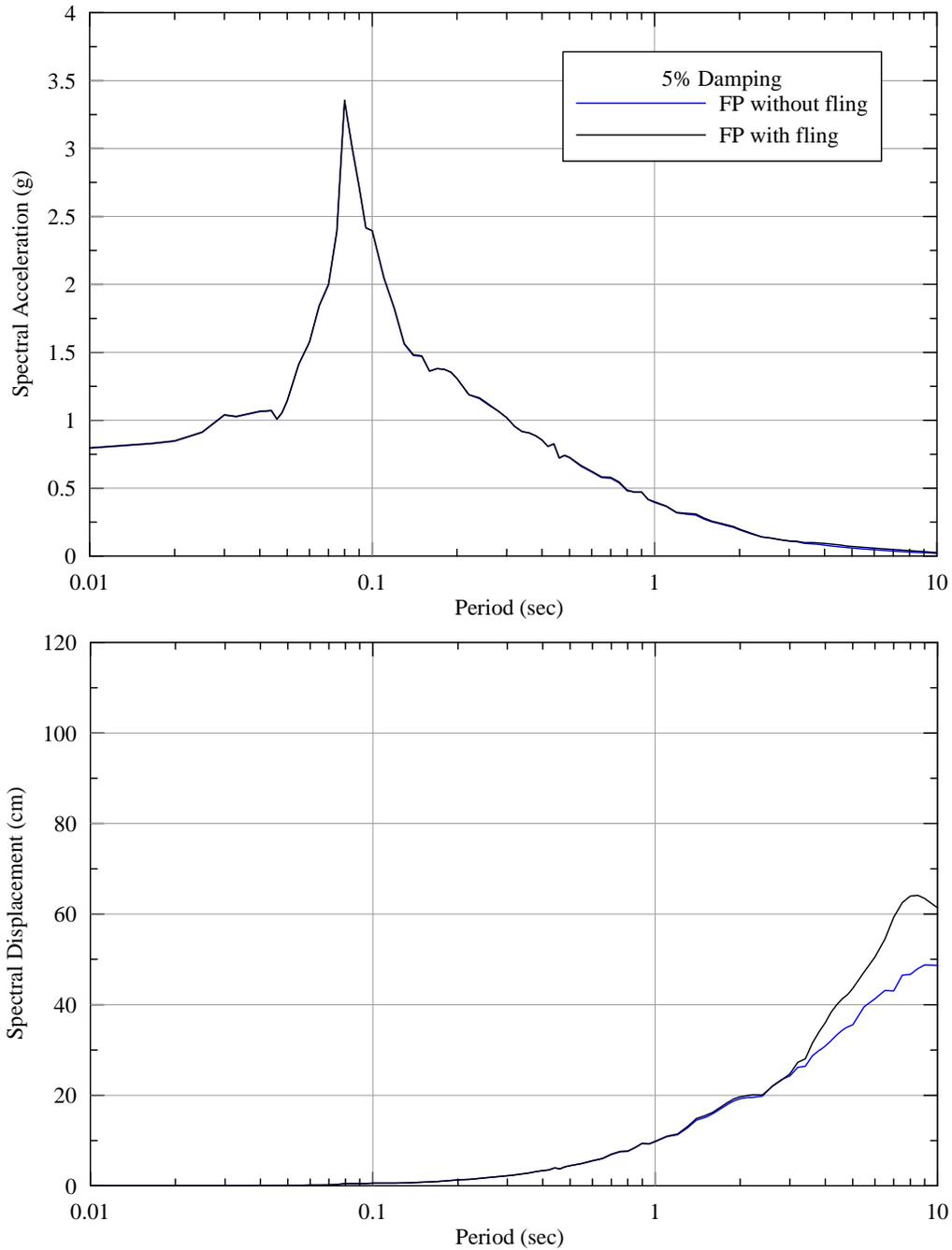


Figure 97: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1999 Kocaeli Earthquake

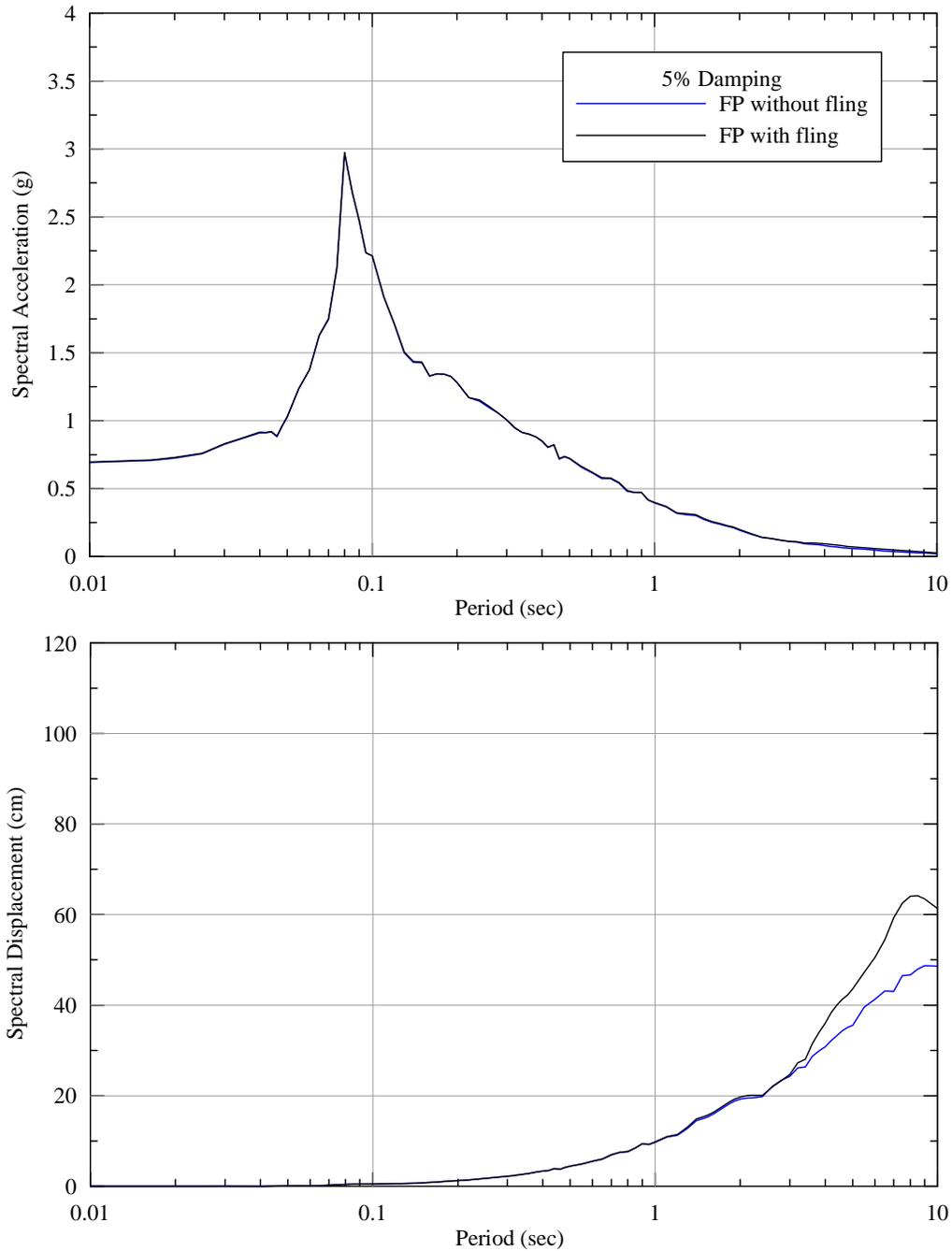


Figure 98: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1999 Kocaeli Earthquake

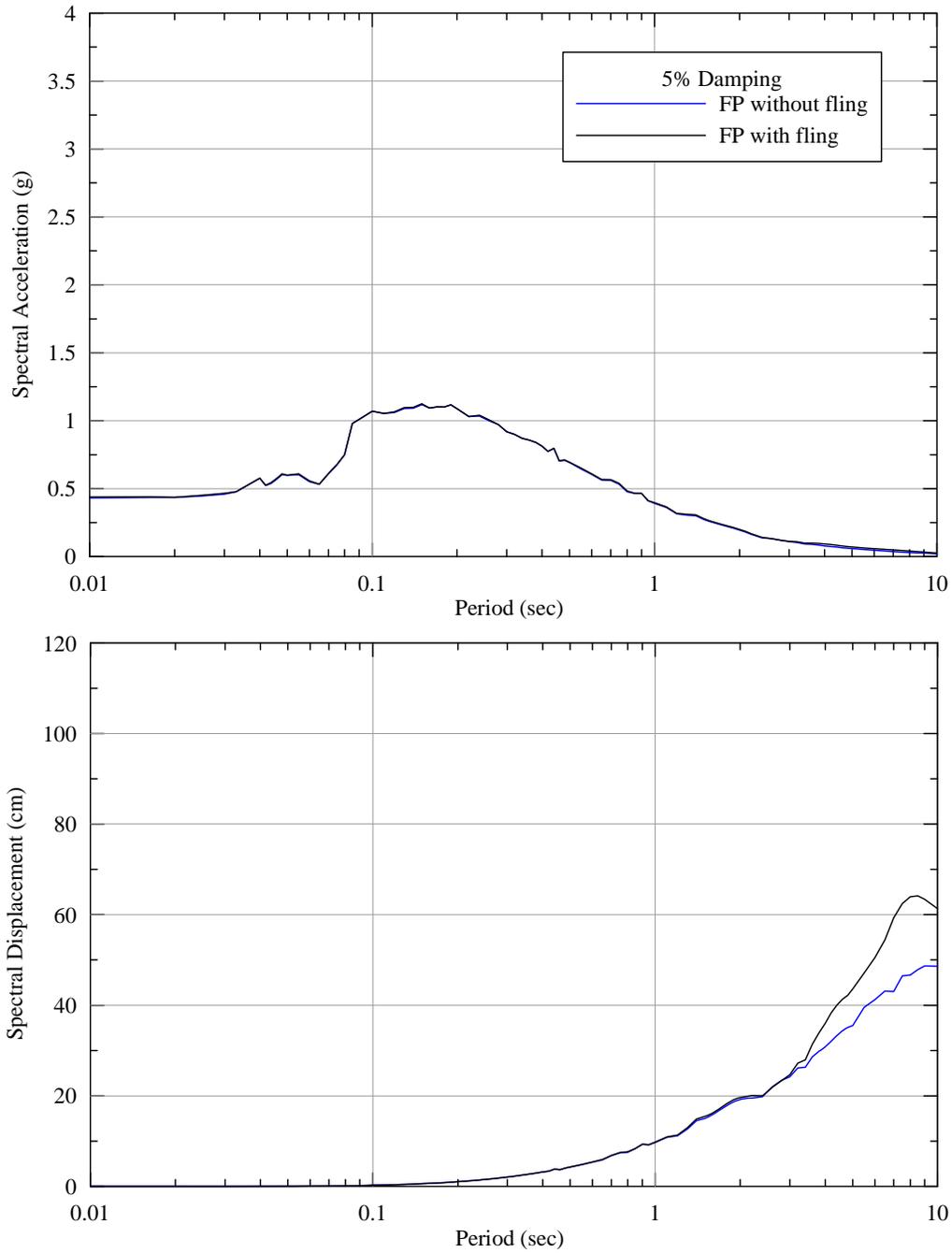


Figure 99: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1999 Kocaeli Earthquake

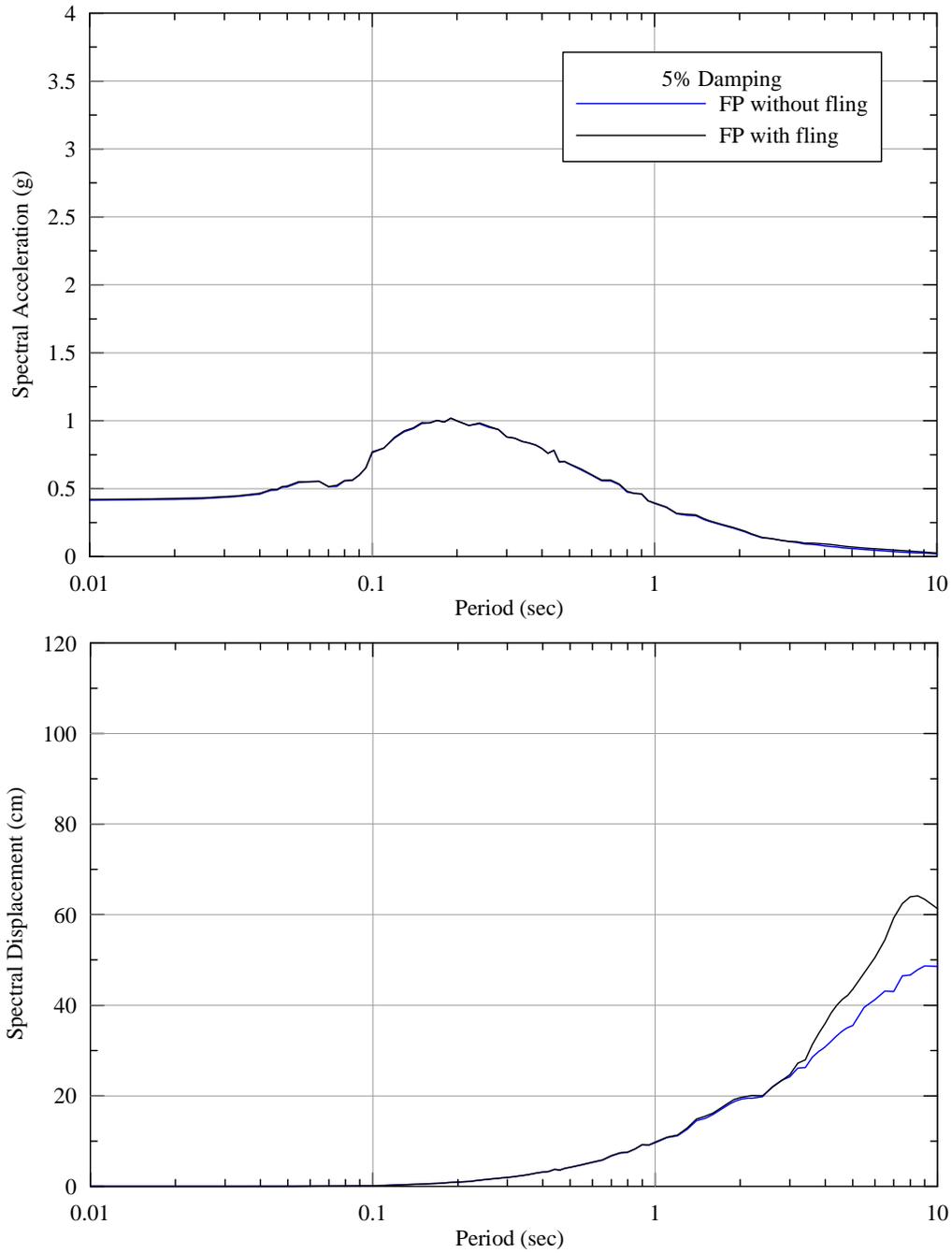


Figure 100: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1999 Kocaeli Earthquake

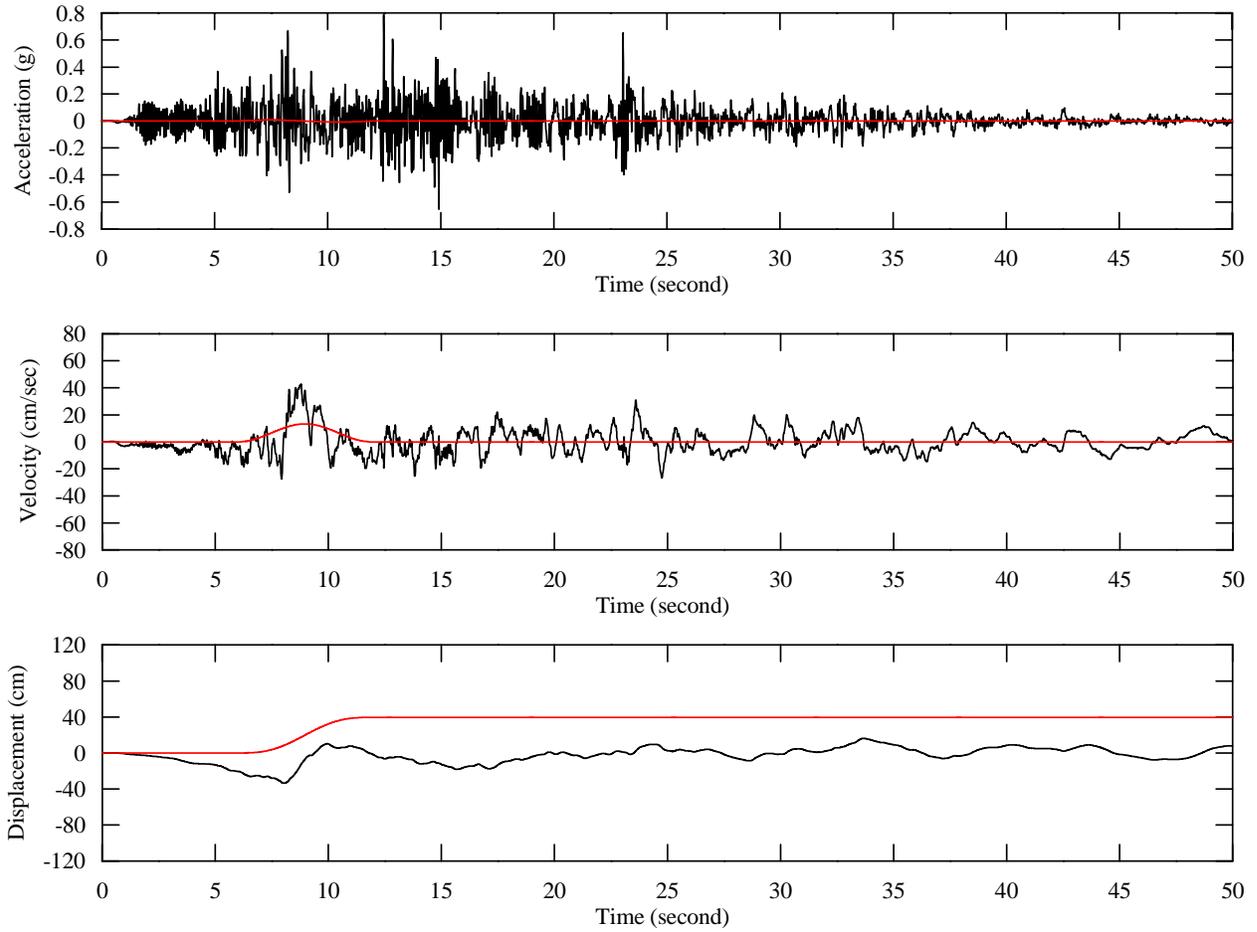


Figure 101: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

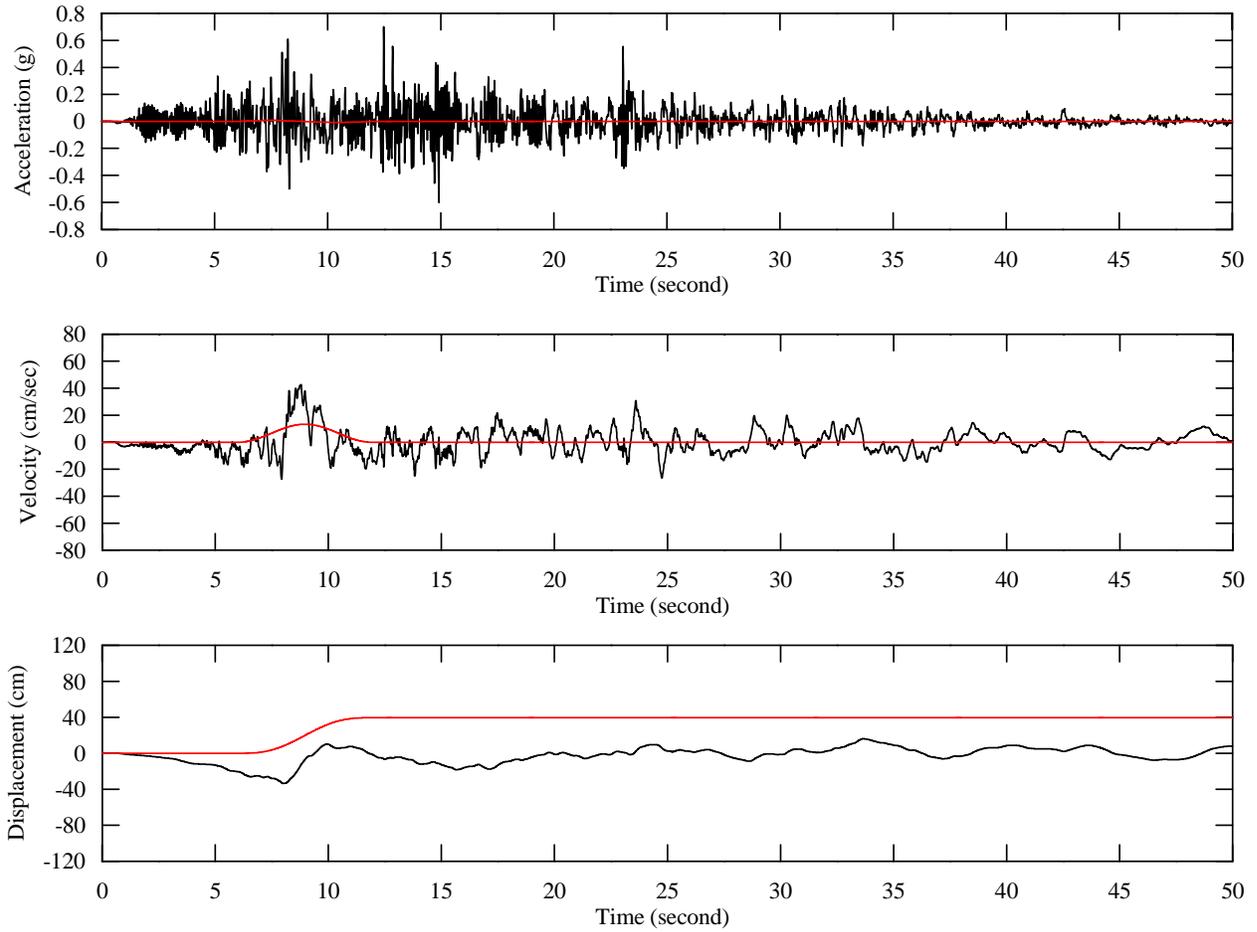


Figure 102: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

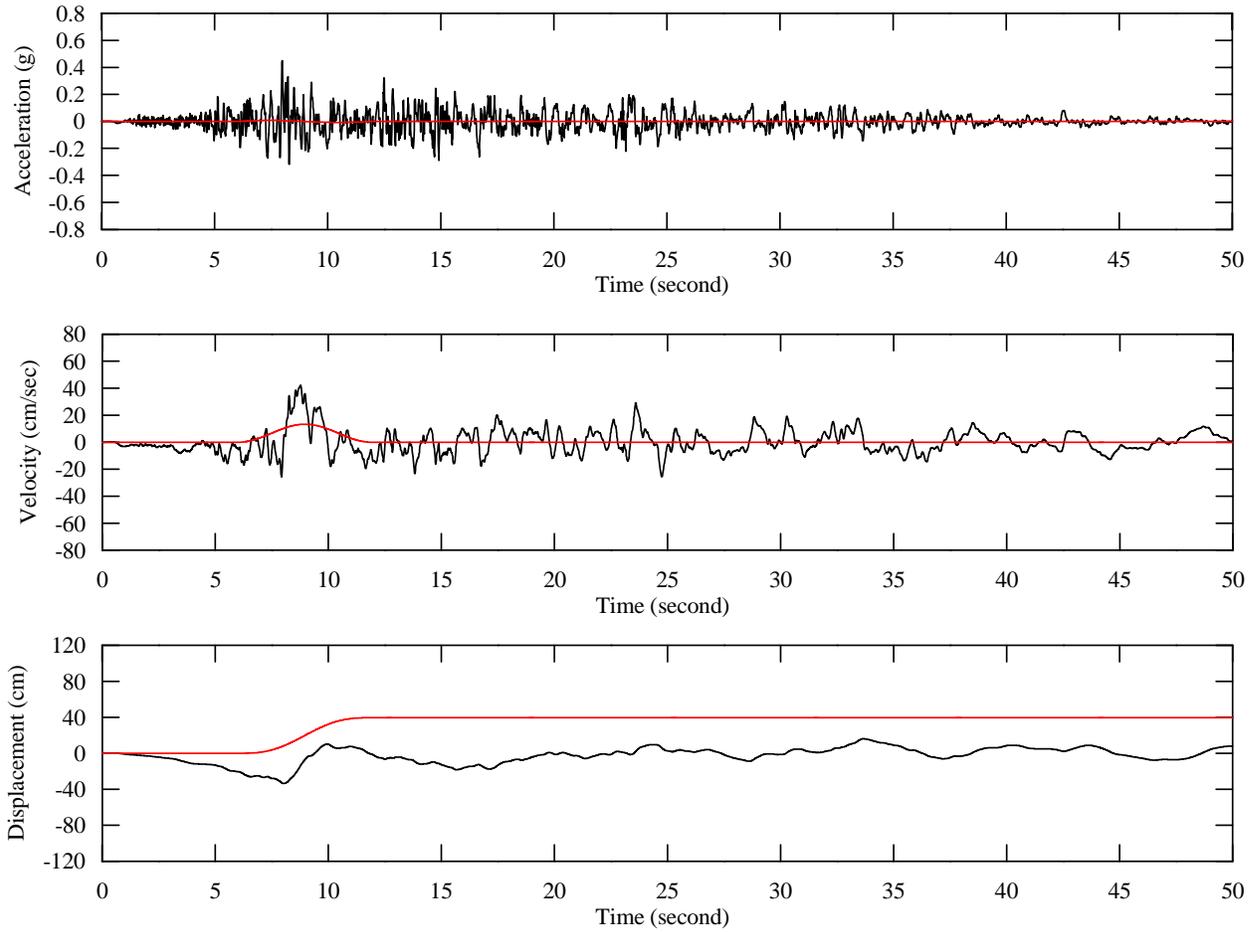


Figure 103: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

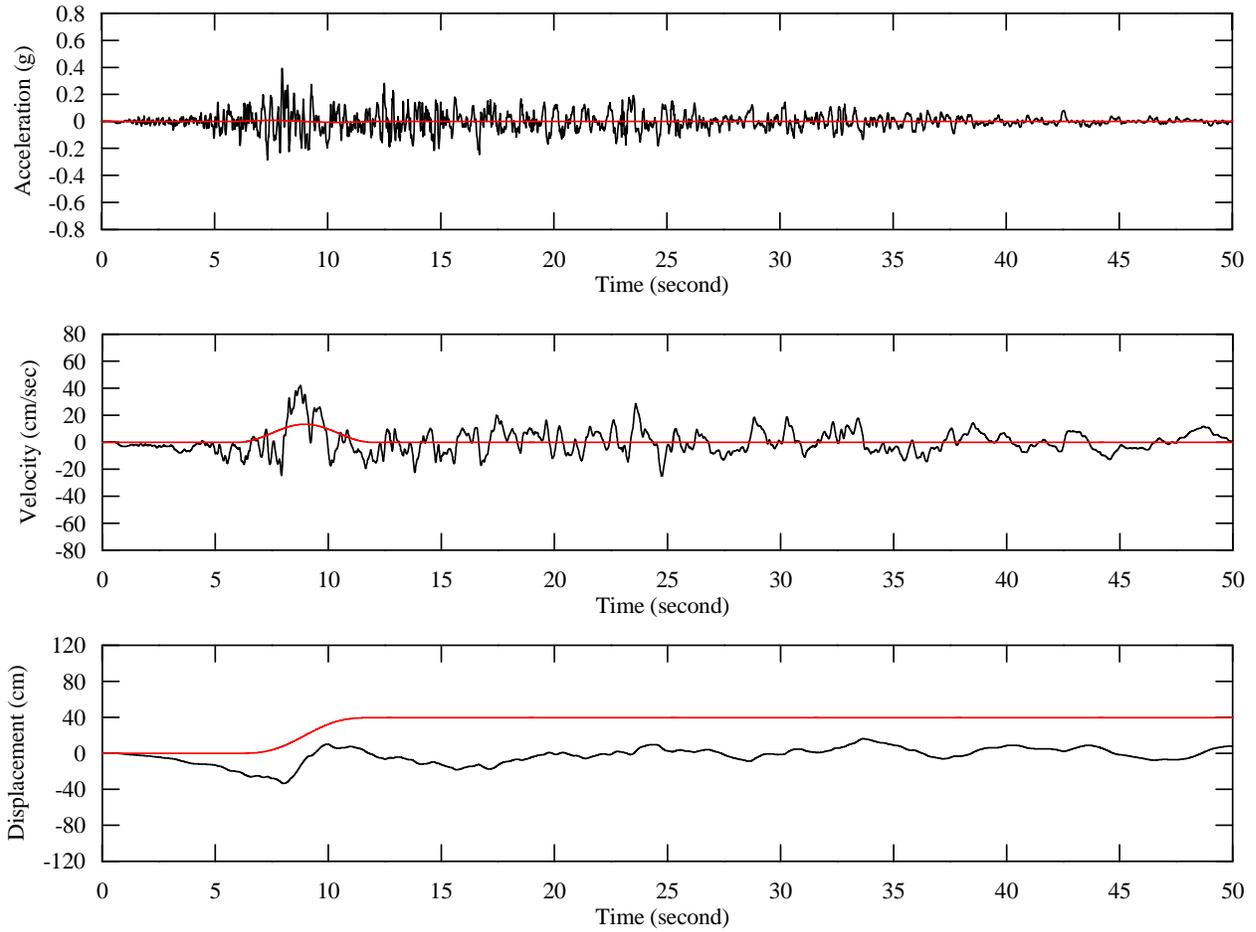


Figure 104: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

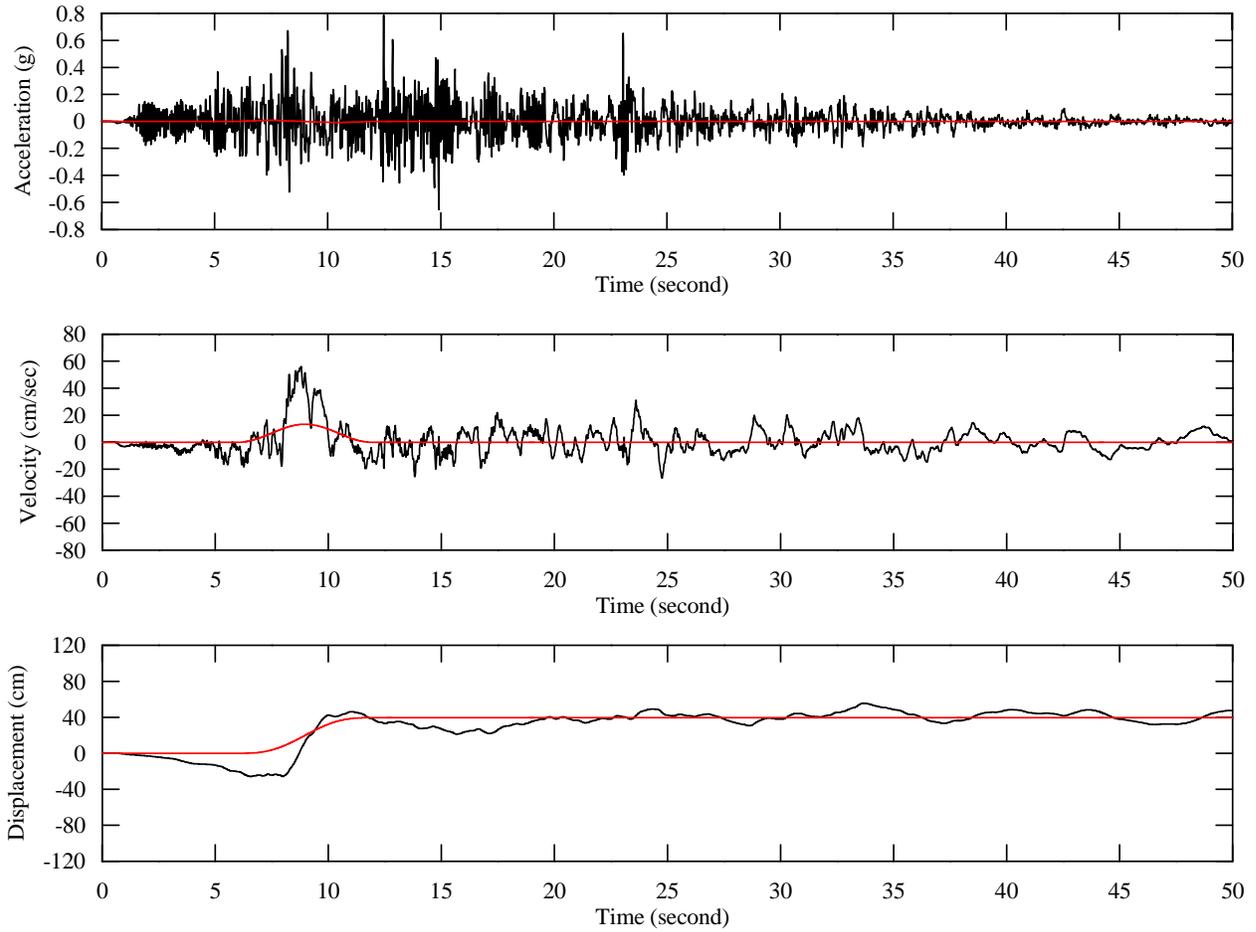


Figure 105: Fault parallel time histories including fling at ground surface, 1999 Chi-Chi Earthquake

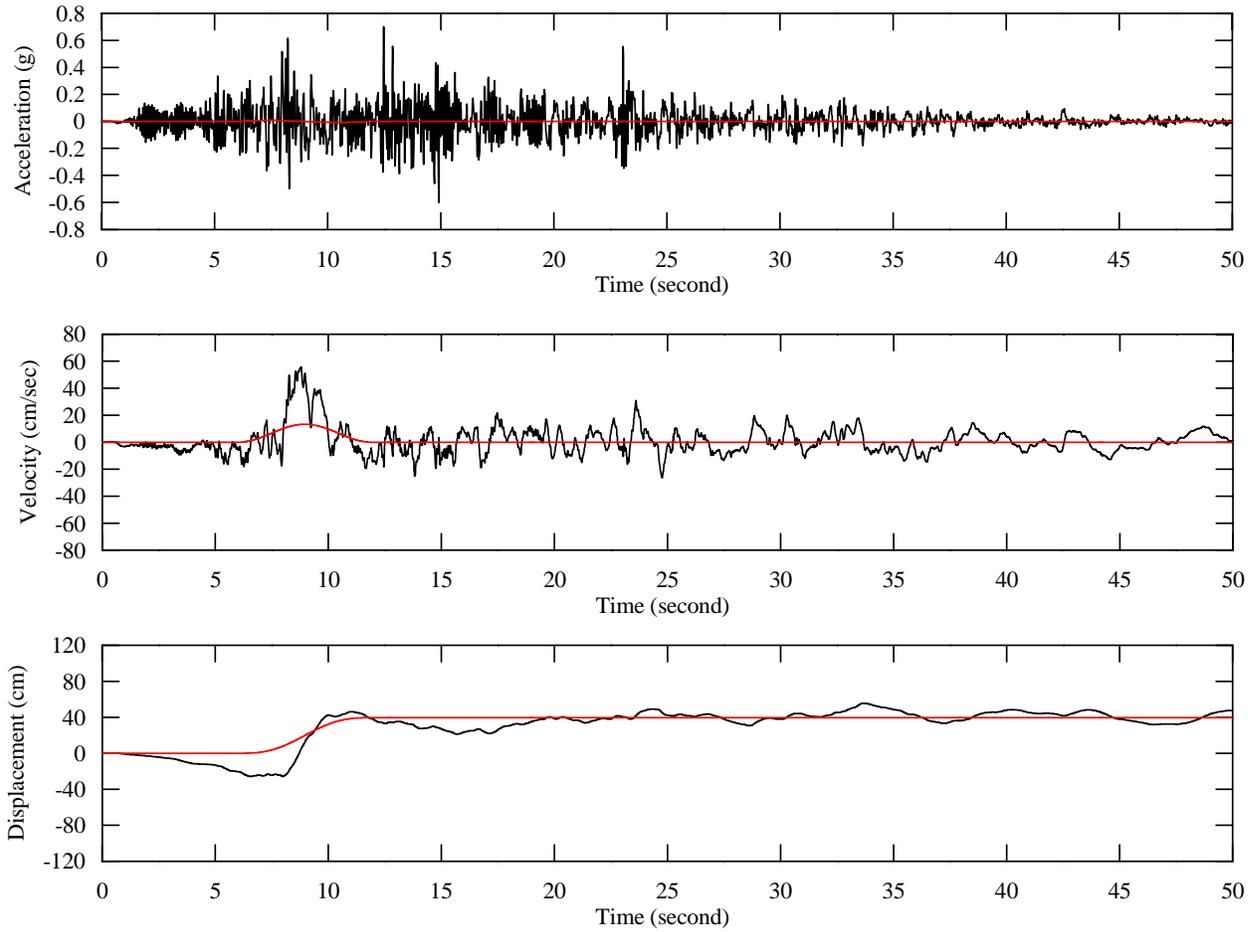


Figure 106: Fault parallel time histories including fling at crown of the tunnel, 1999 Chi-Chi Earthquake

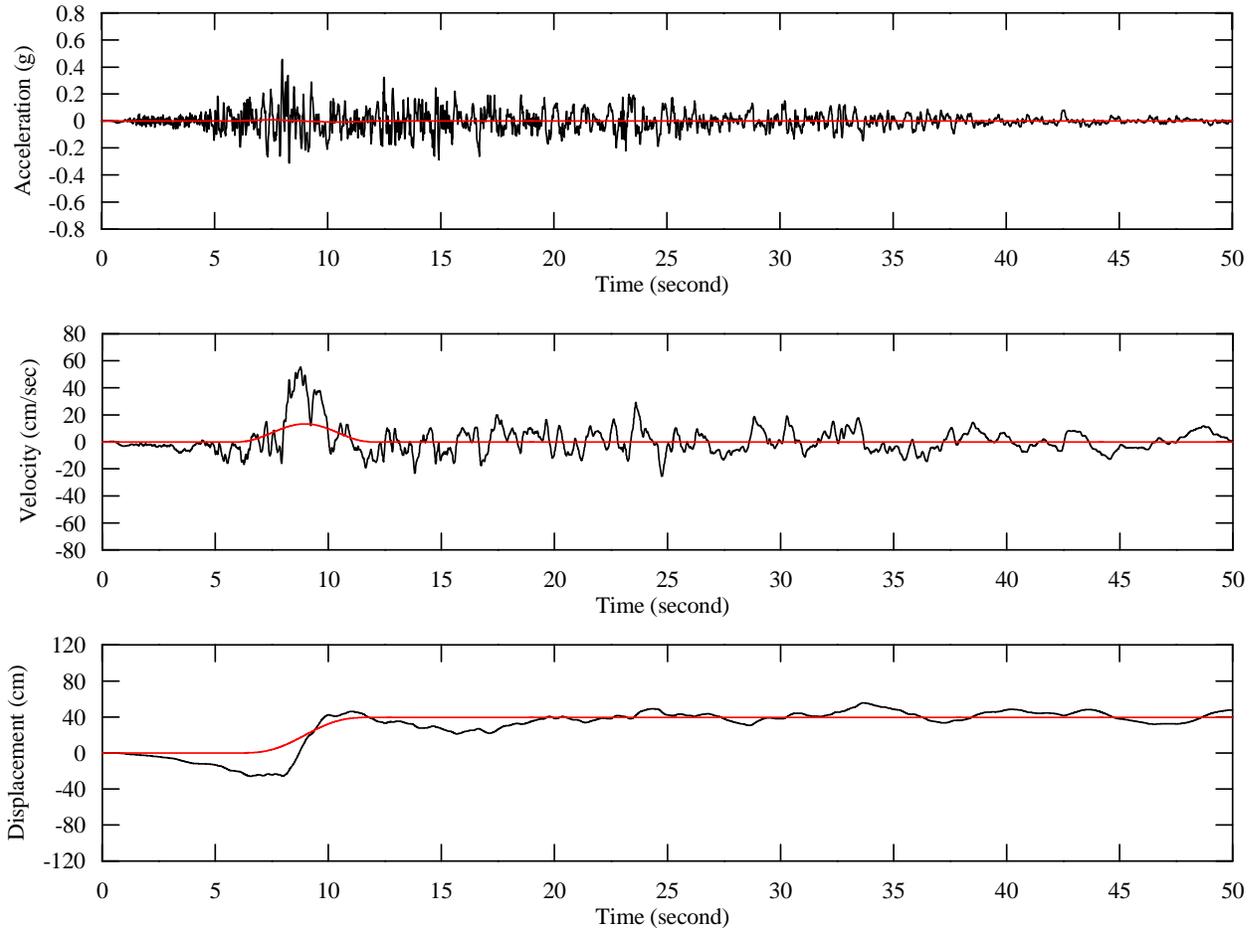


Figure 107: Fault parallel time histories including fling at top of side wall, 1999 Chi-Chi Earthquake

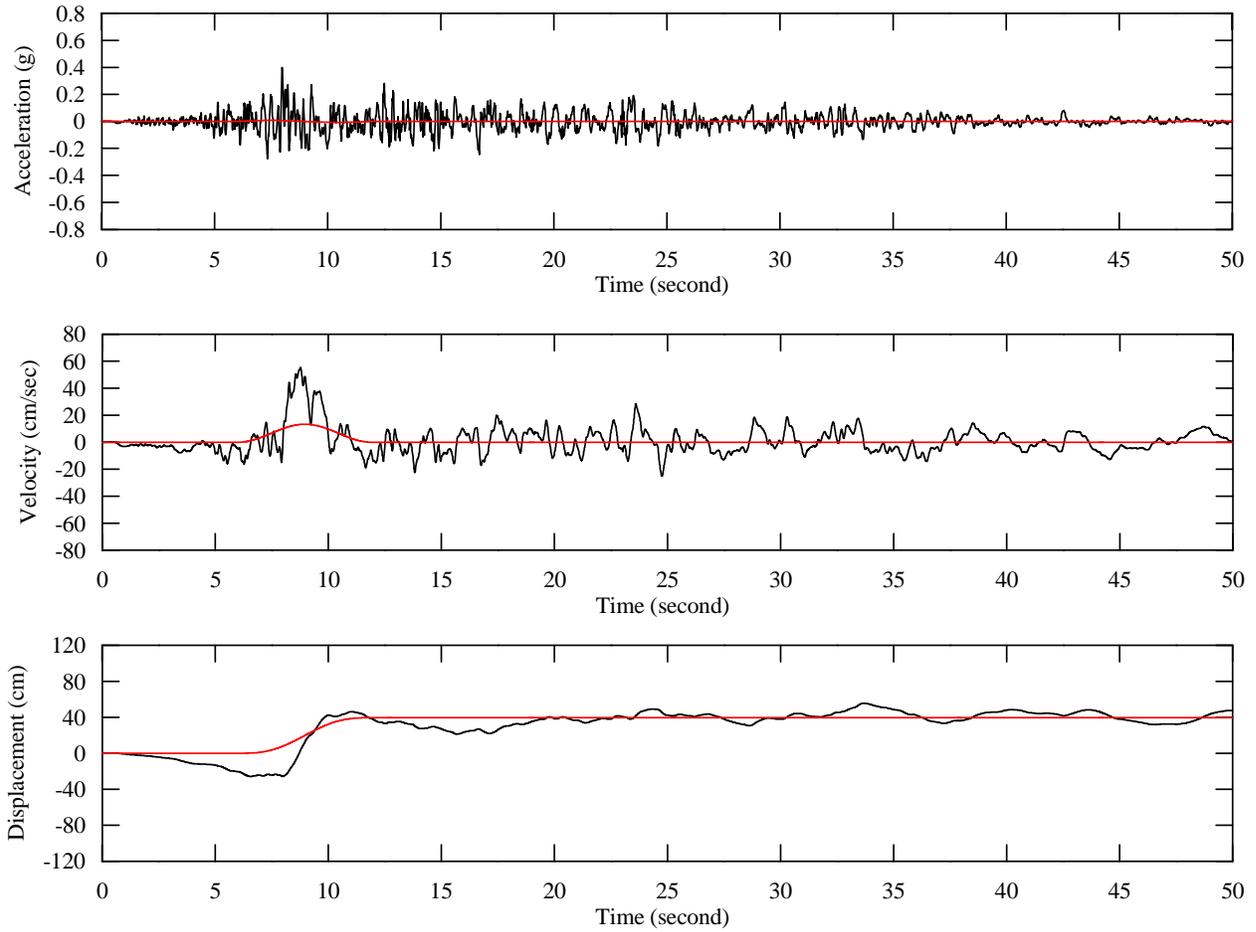


Figure 108: Fault parallel time histories including fling at invert of the tunnel, 1999 Chi-Chi Earthquake

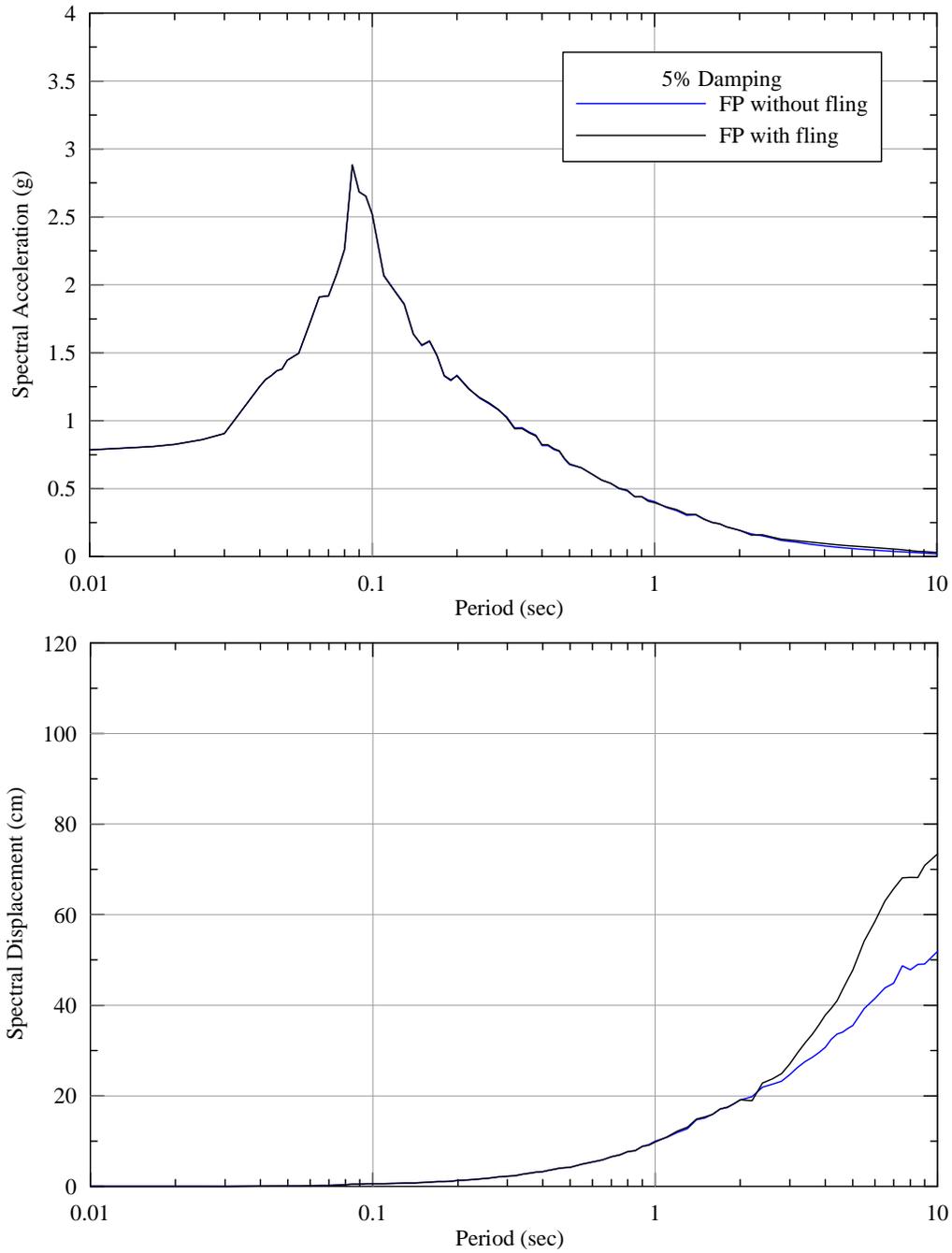


Figure 109: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1999 Chi-Chi Earthquake

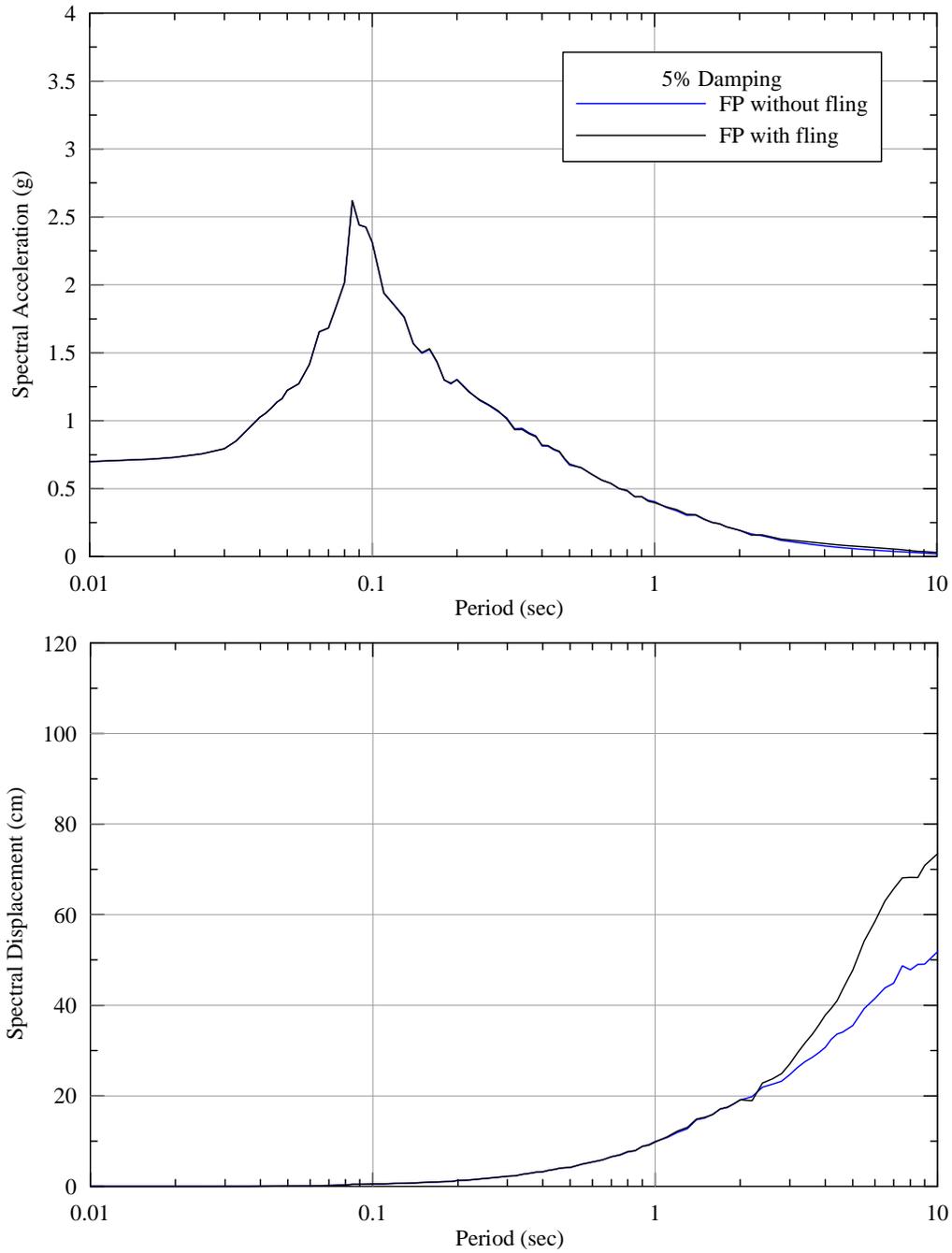


Figure 110: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1999 Chi-Chi Earthquake

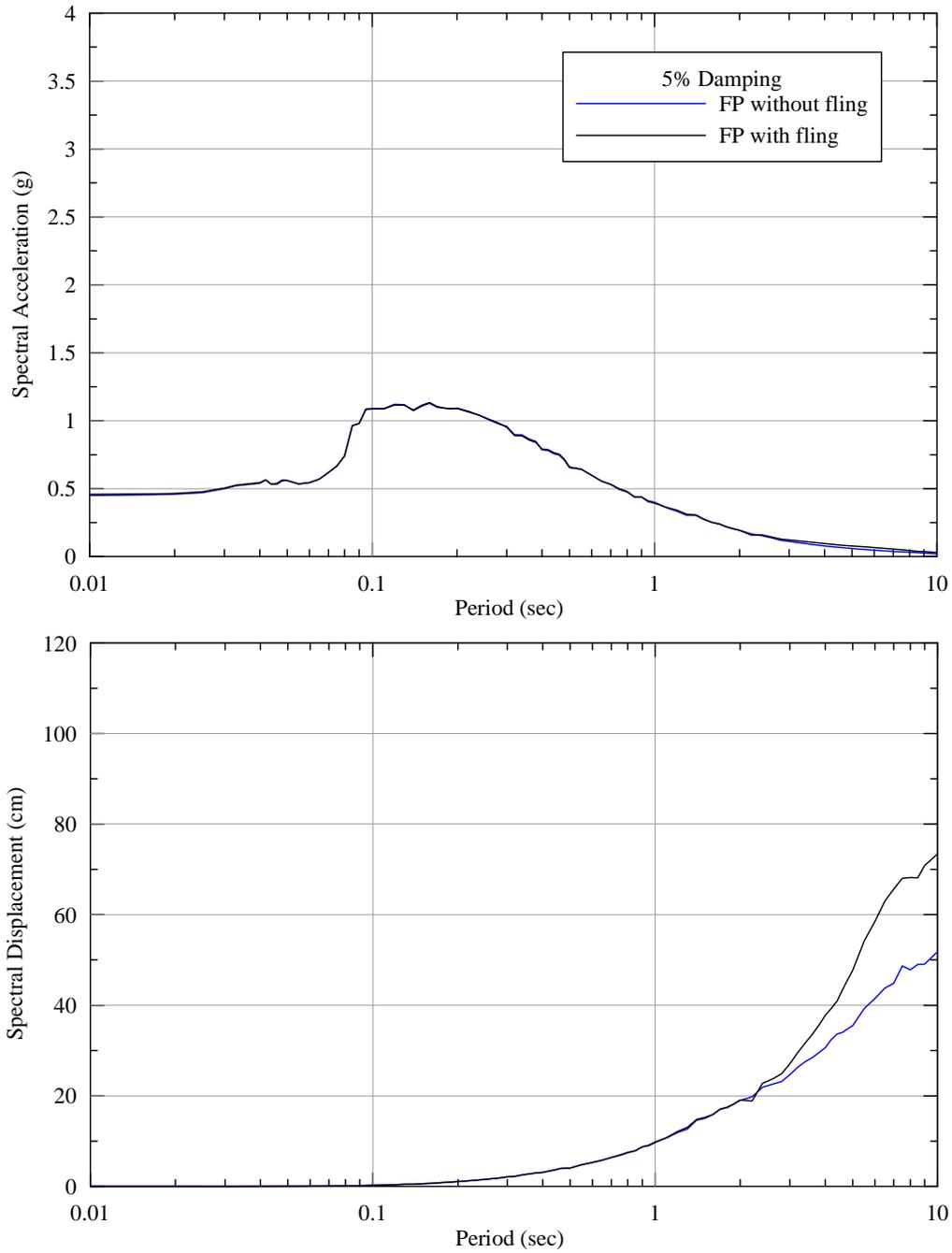


Figure 111: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1999 Chi-Chi Earthquake

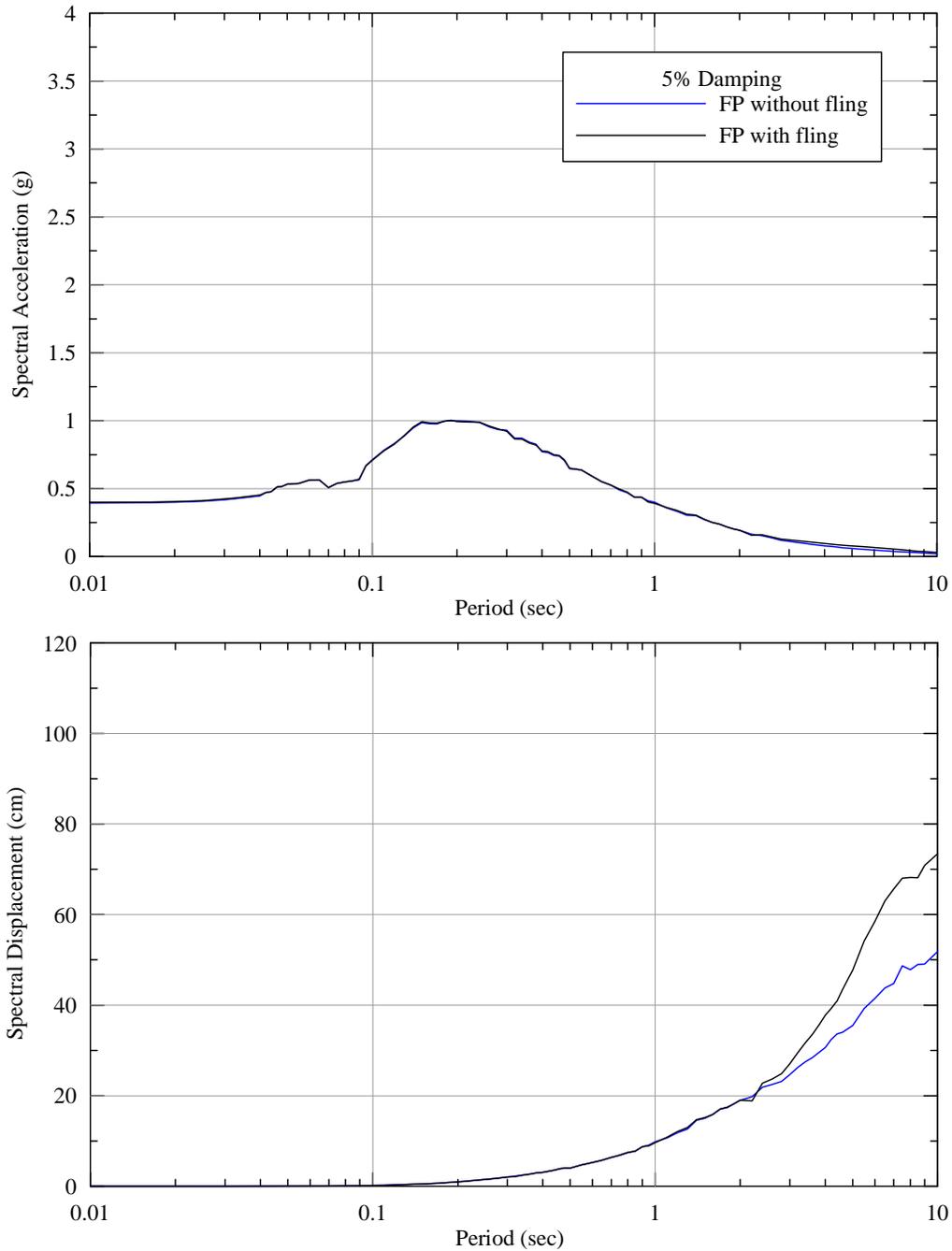


Figure 112: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1999 Chi-Chi Earthquake

NORTH MAIN POST TUNNEL (DEEP) PROFILE

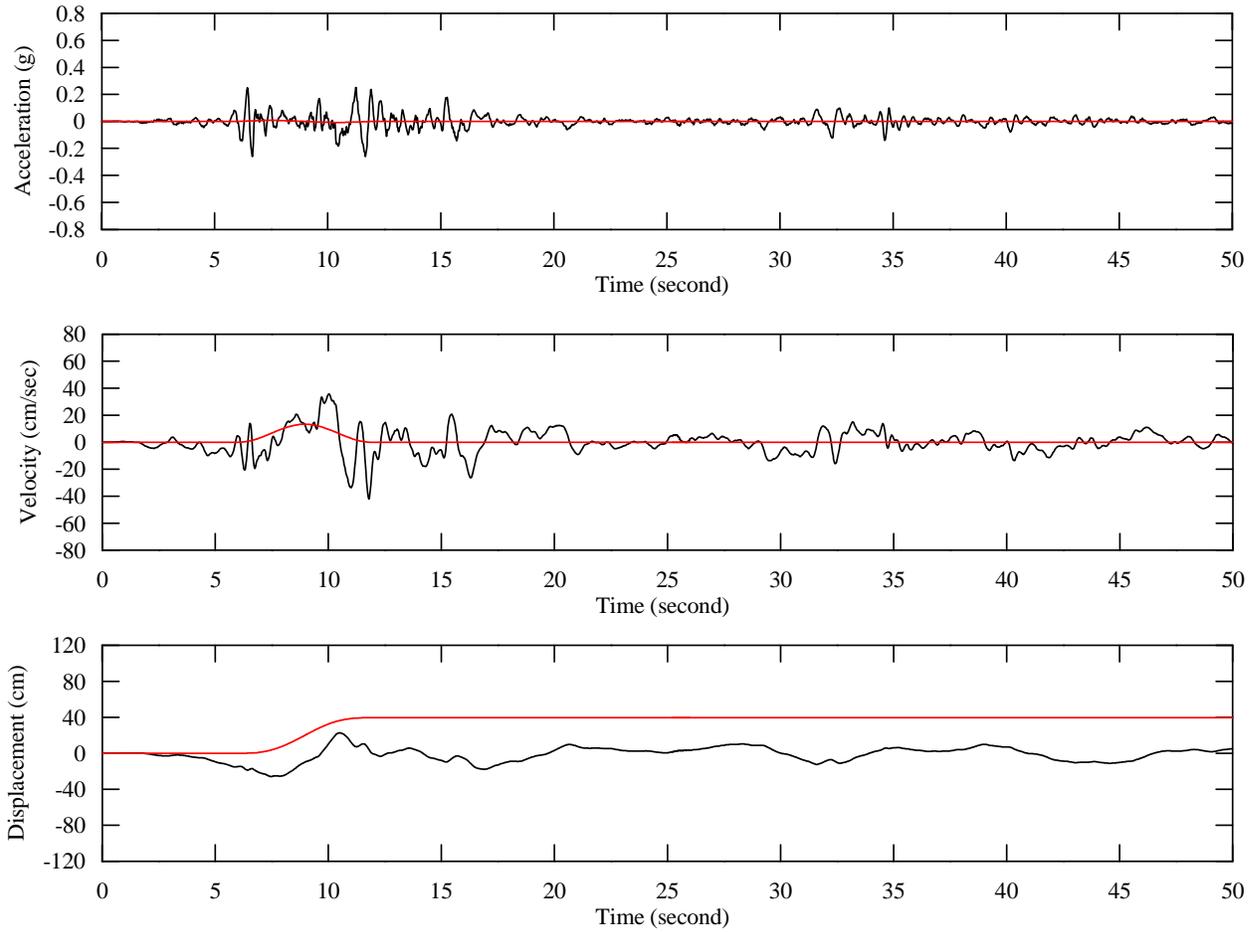


Figure 113: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1990 Manjil Earthquake

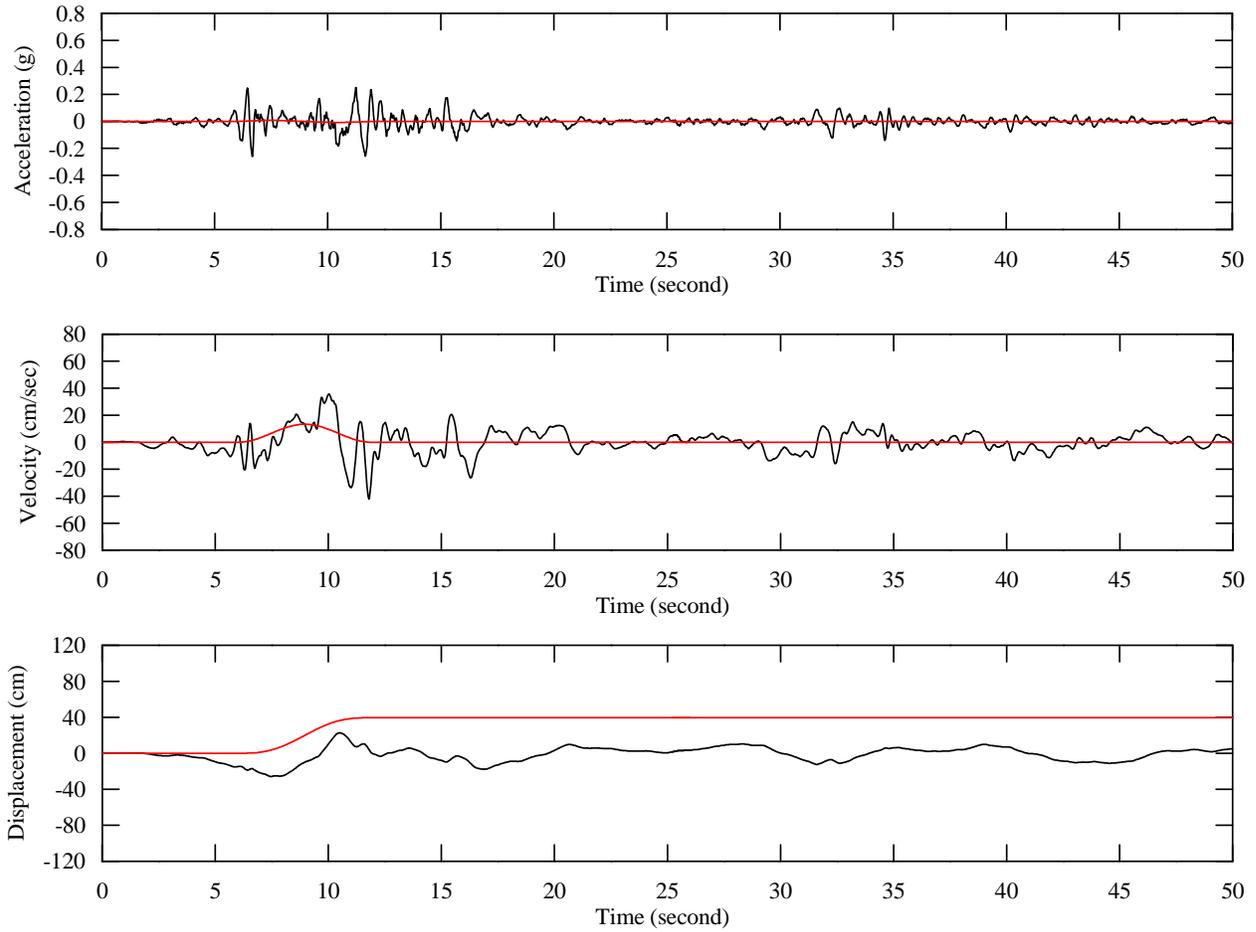


Figure 114: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1990 Manjil Earthquake

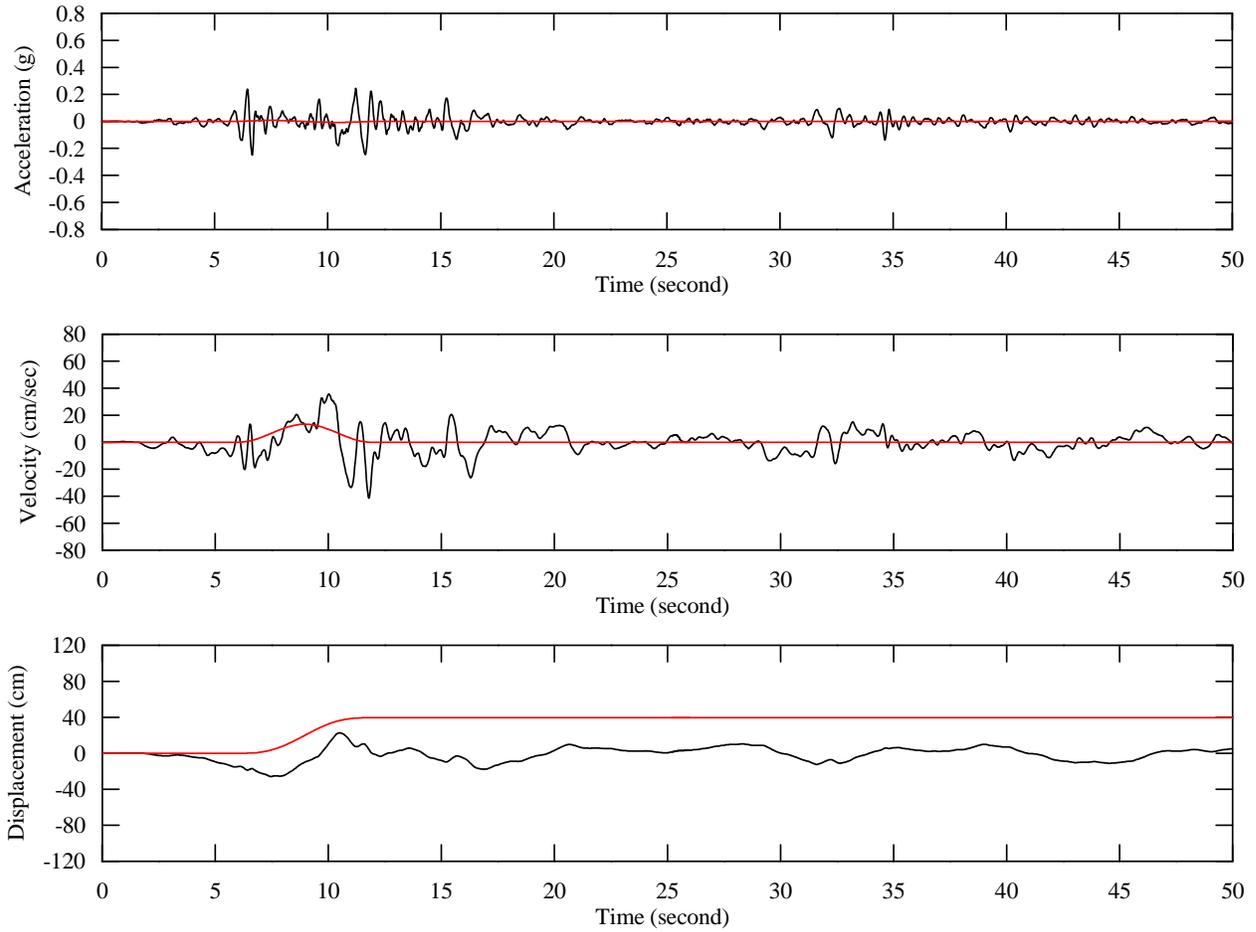


Figure 115: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1990 Manjil Earthquake

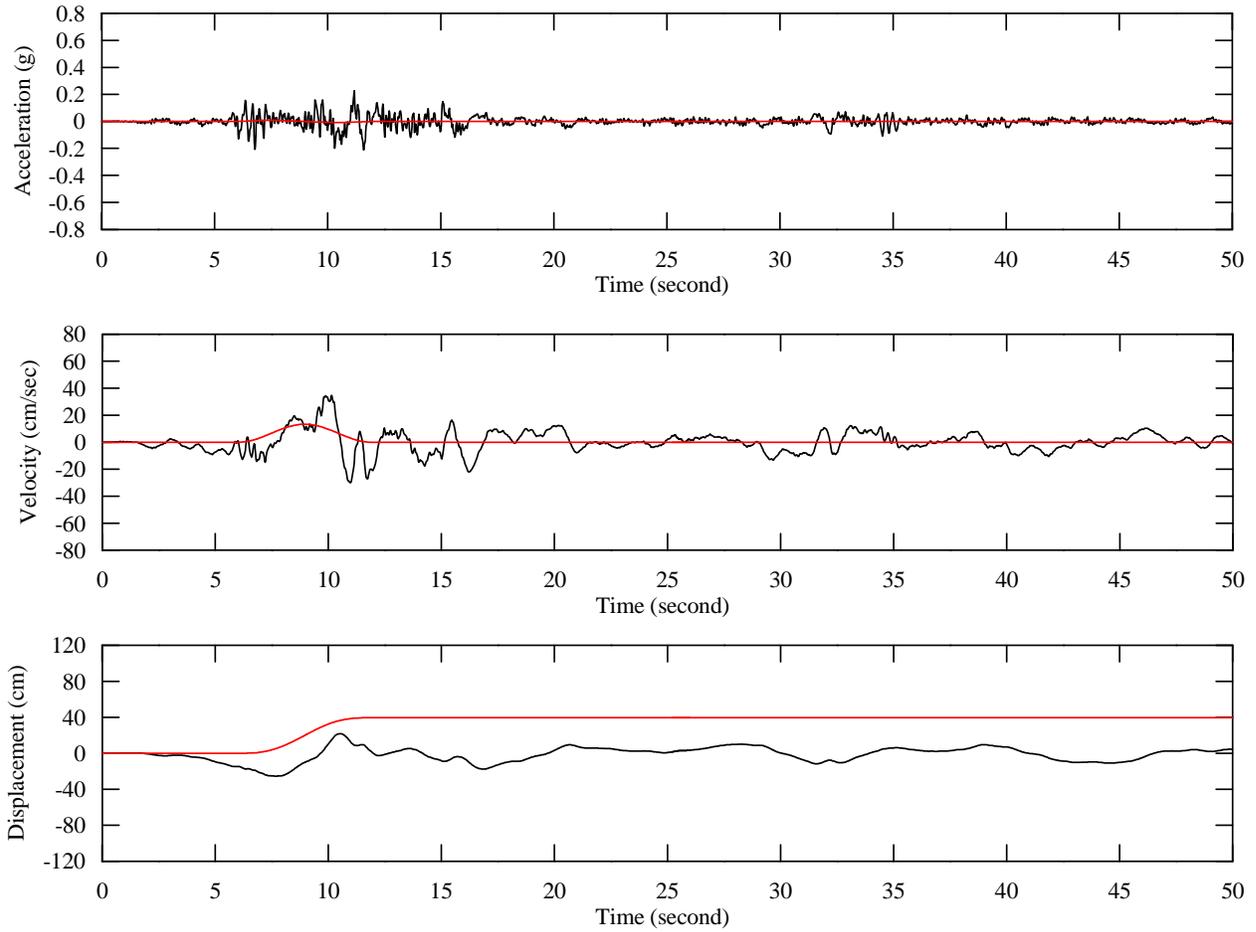


Figure 116: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1990 Manjil Earthquake

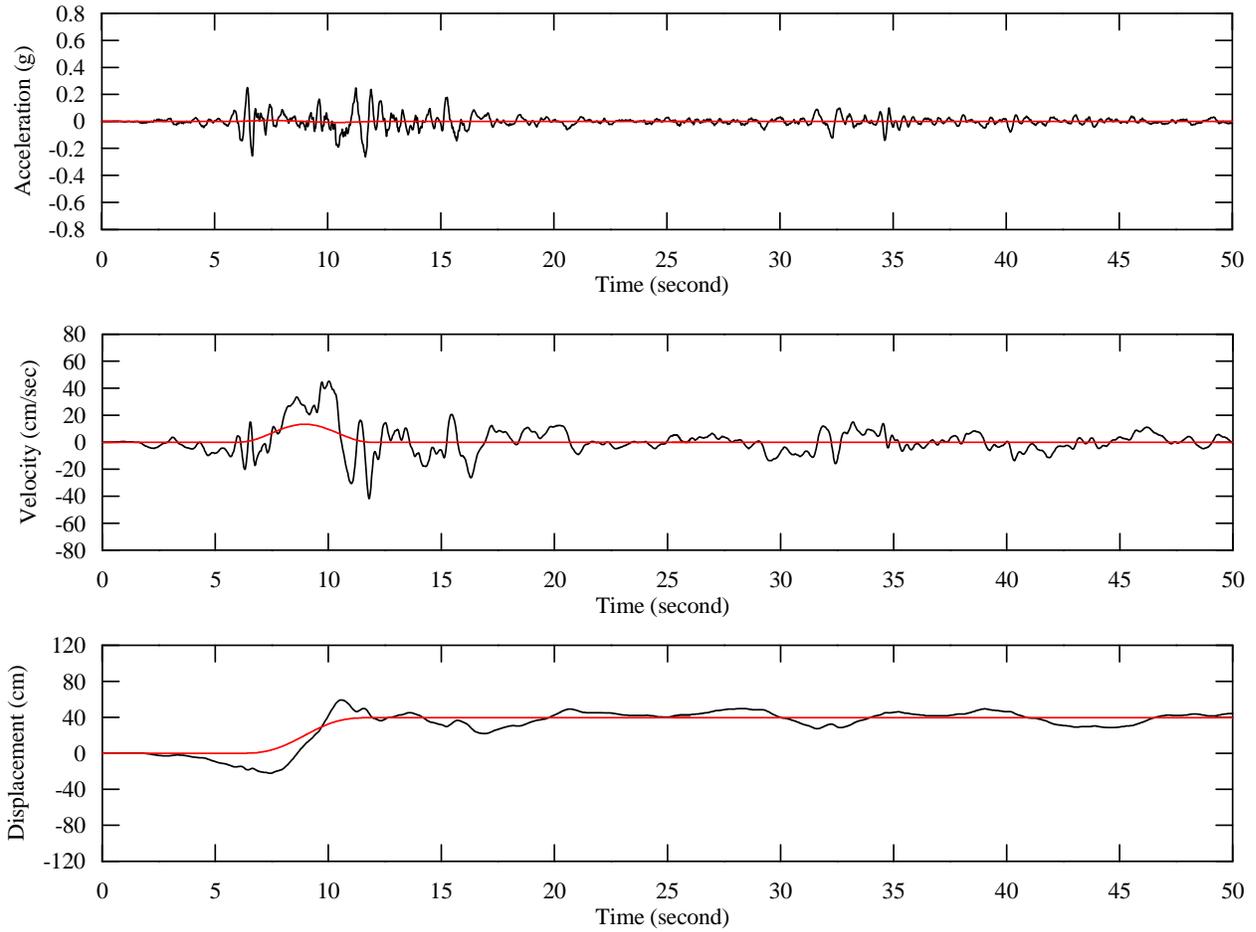


Figure 117: Fault parallel time histories including fling at ground surface, 1990 Manjil Earthquake

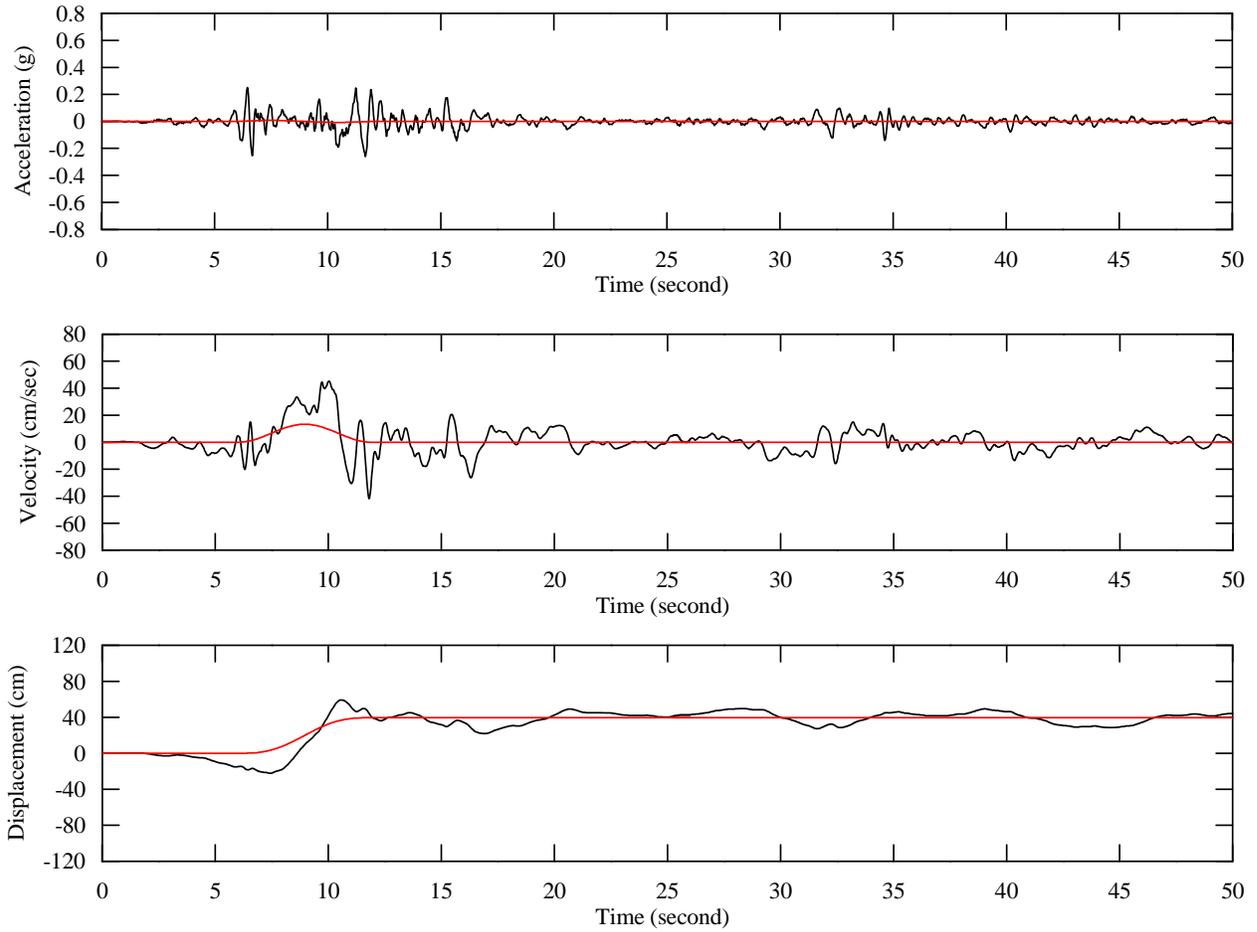


Figure 118: Fault parallel time histories including fling at crown of the tunnel, 1990 Manjil Earthquake

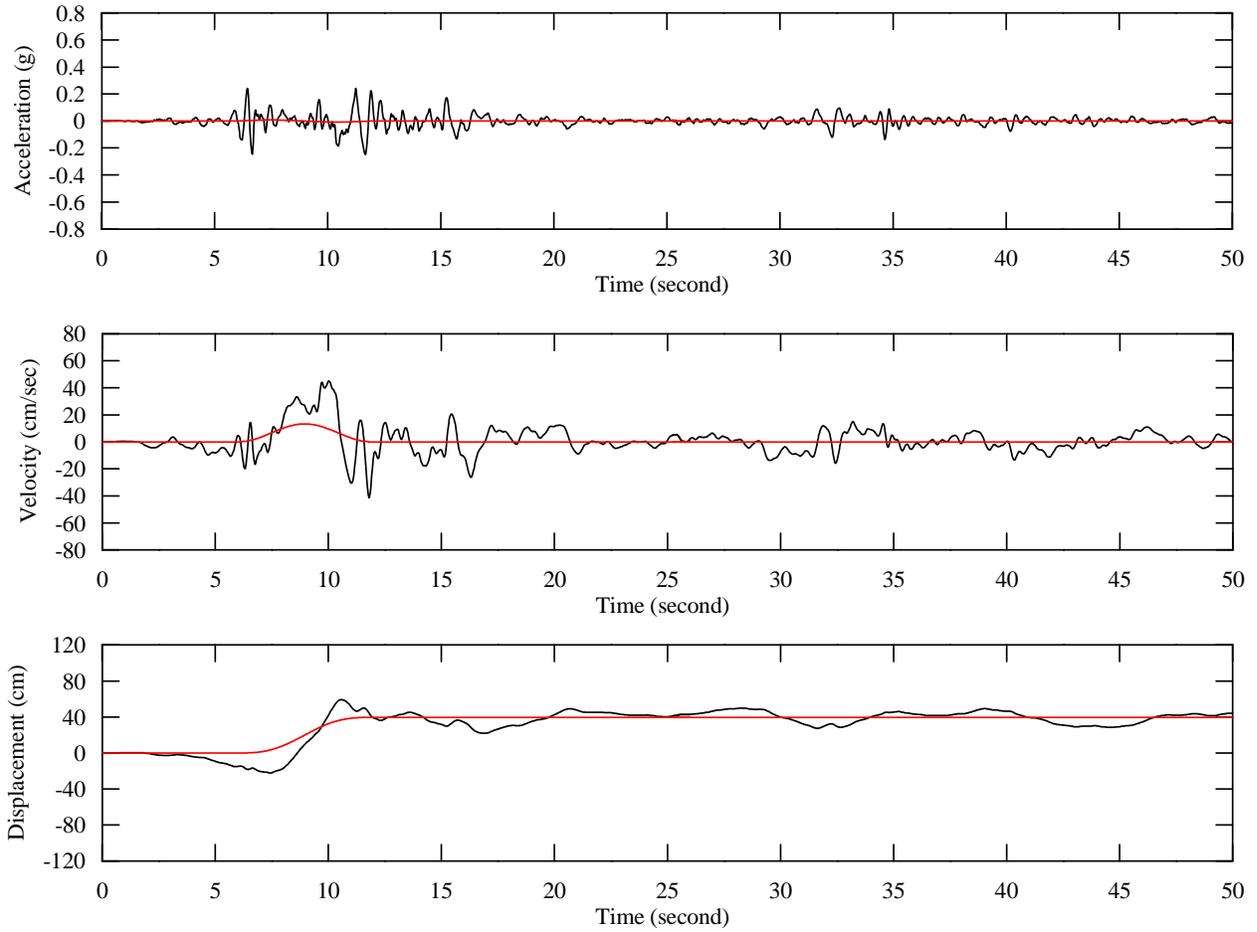


Figure 119: Fault parallel time histories including fling at top of side wall, 1990 Manjil Earthquake

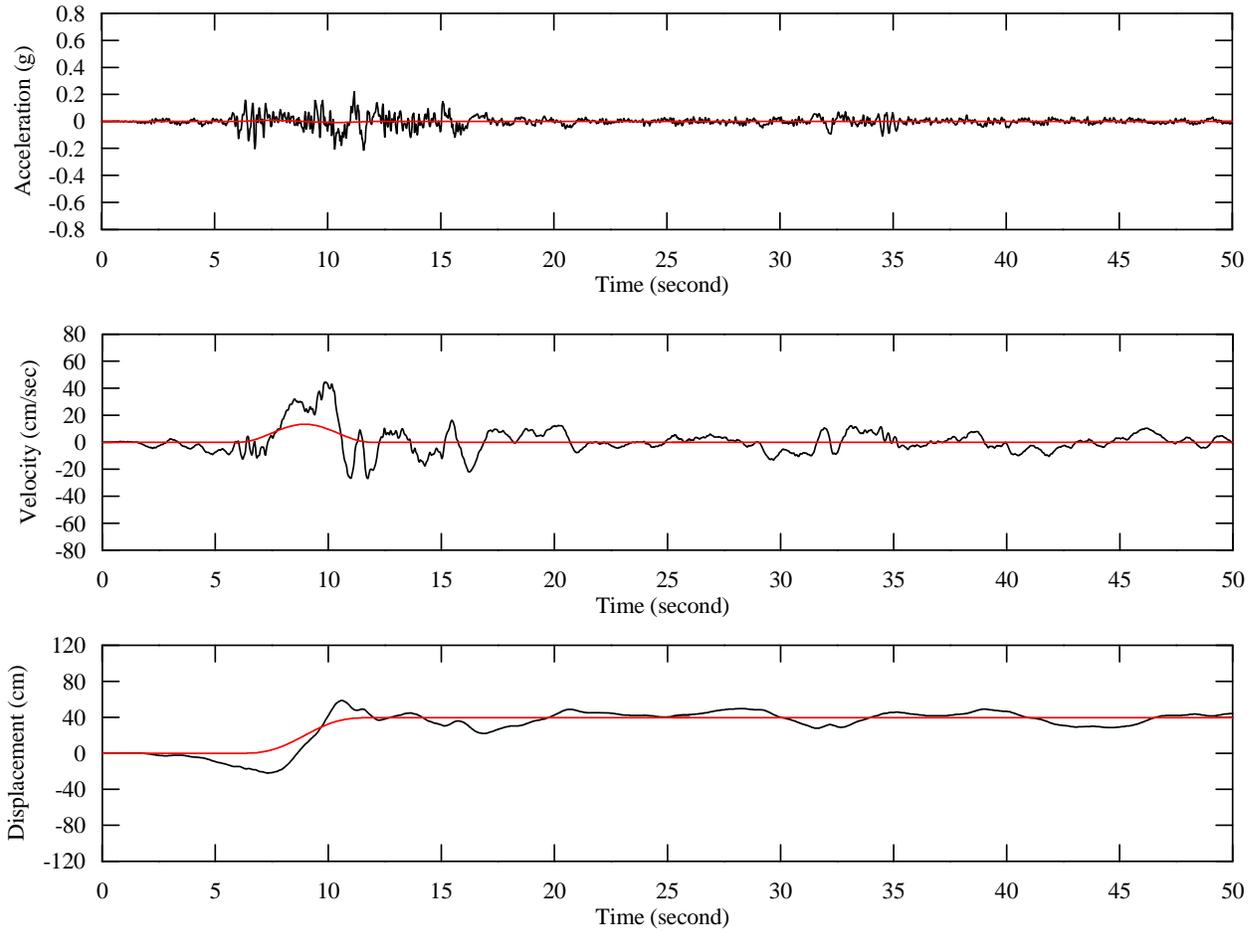


Figure 120: Fault parallel time histories including fling at invert of the tunnel, 1990 Manjil Earthquake

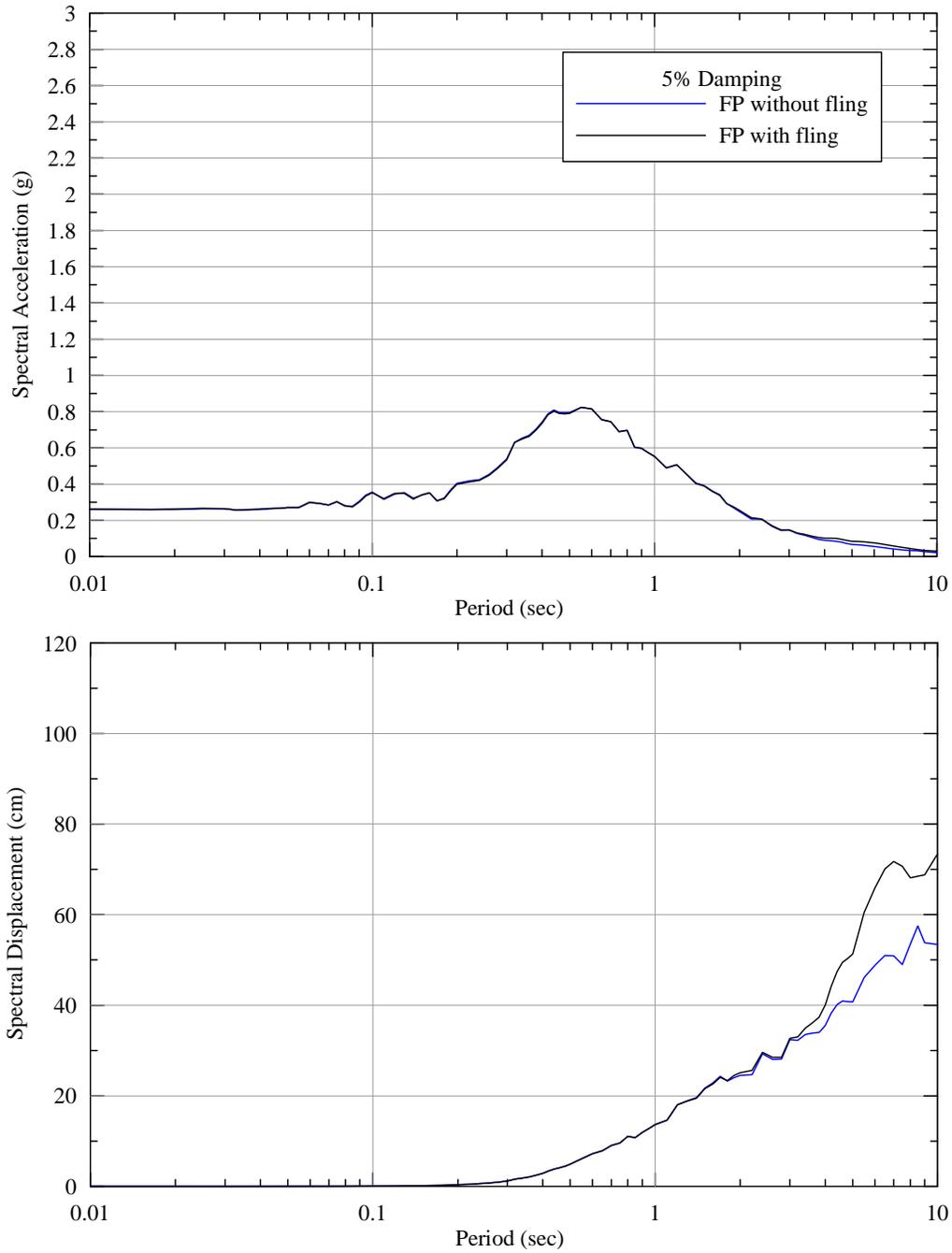


Figure 121: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1990 Manjil Earthquake

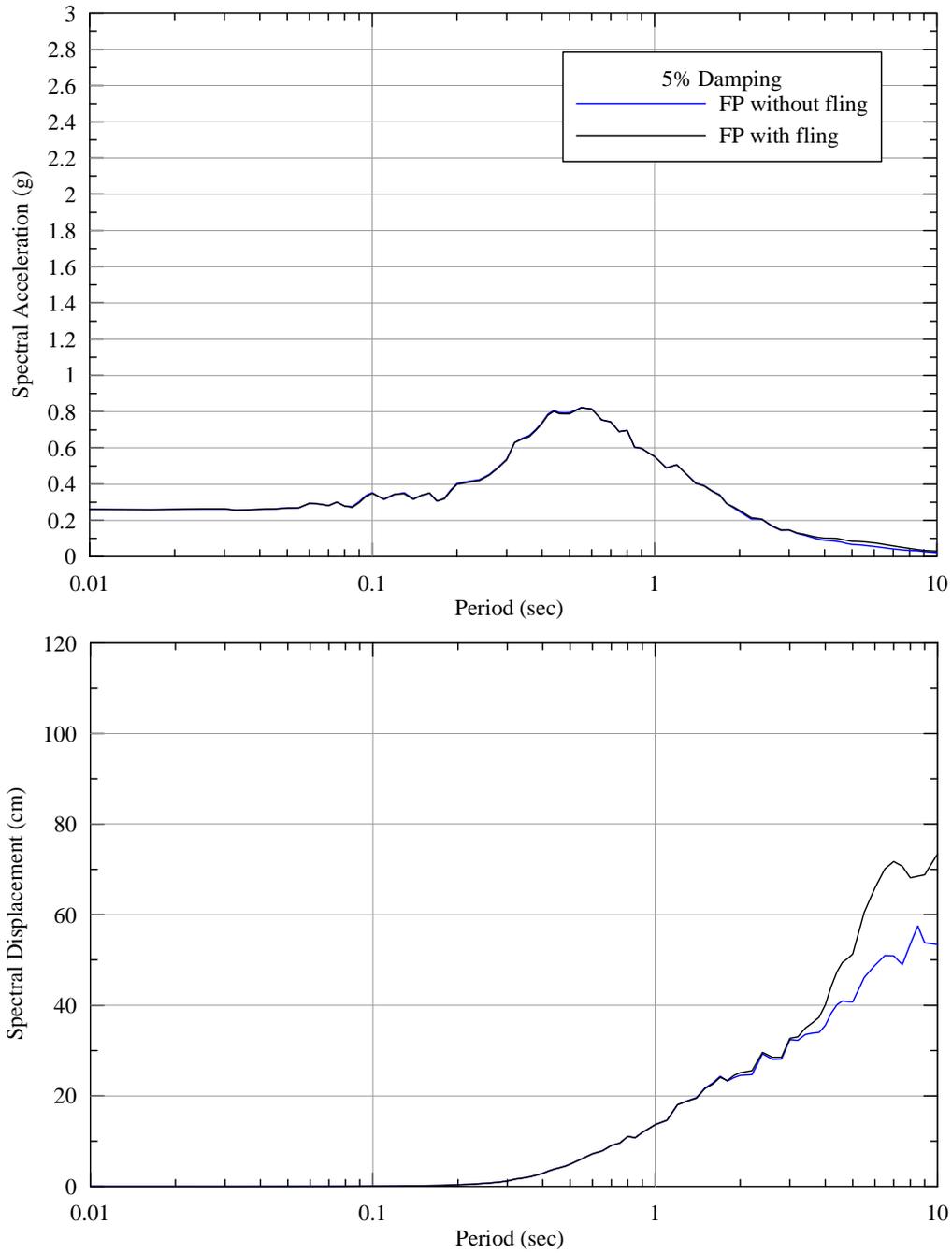


Figure 122: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1990 Manjil Earthquake

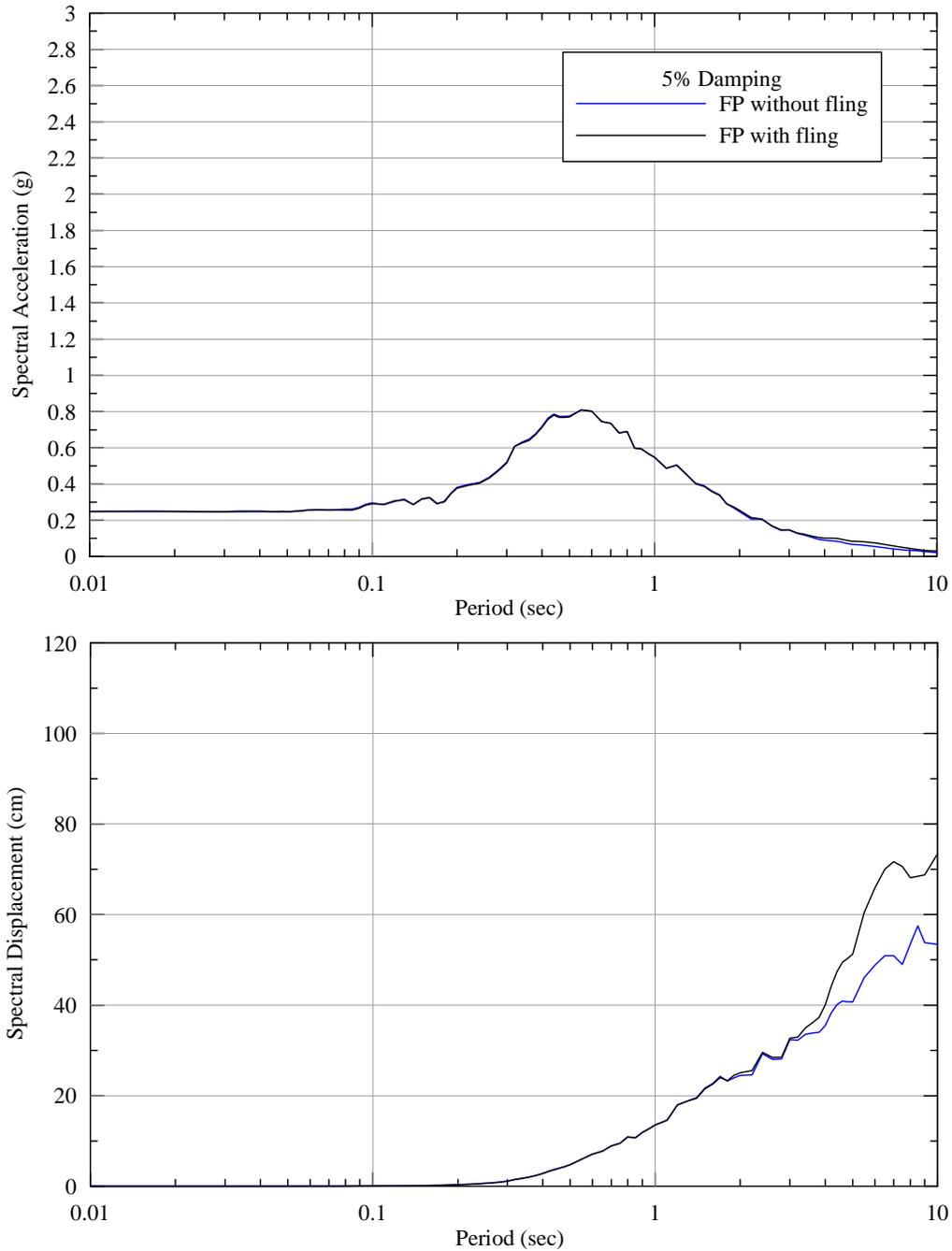


Figure 123: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1990 Manjil Earthquake

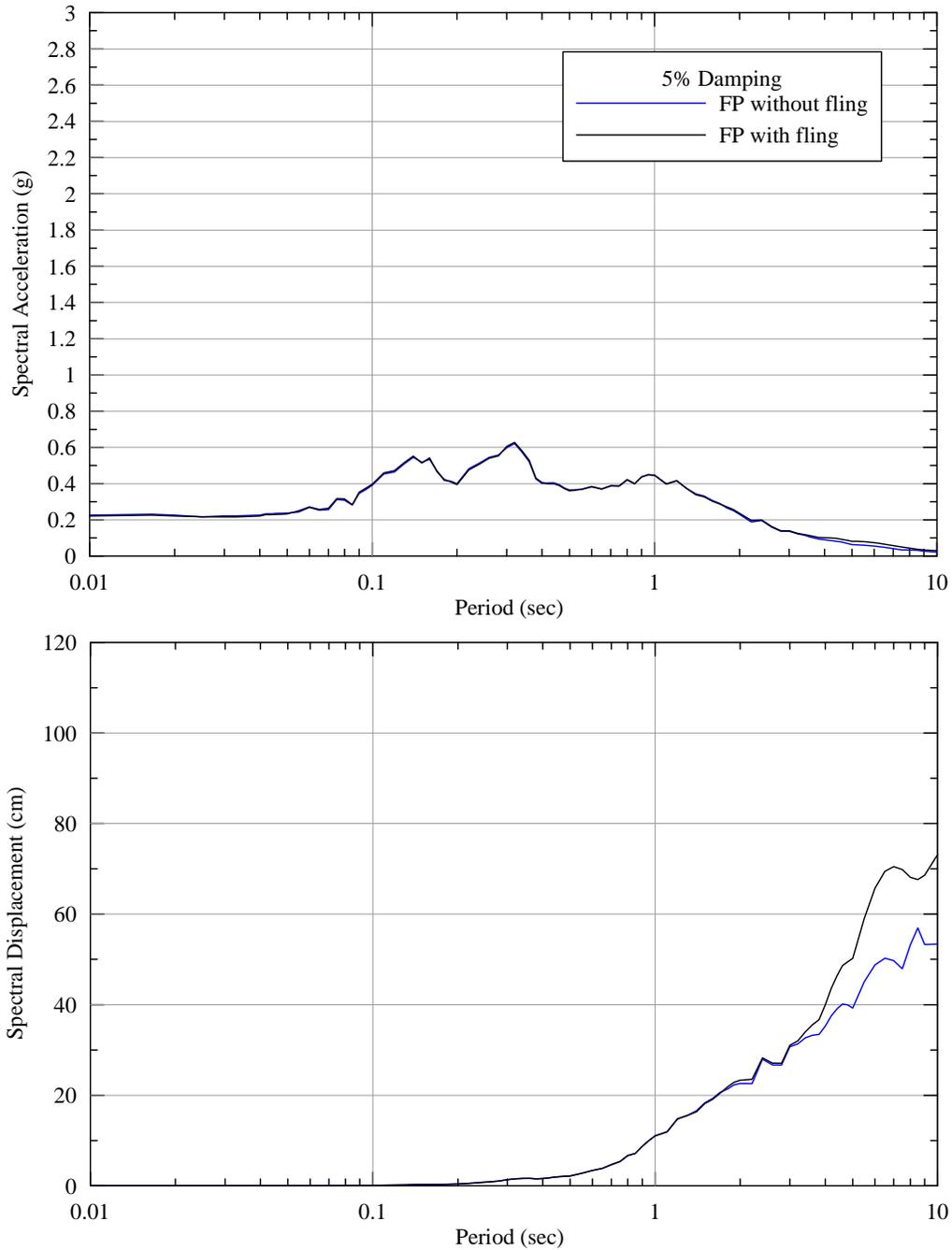


Figure 124: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1990 Manjil Earthquake

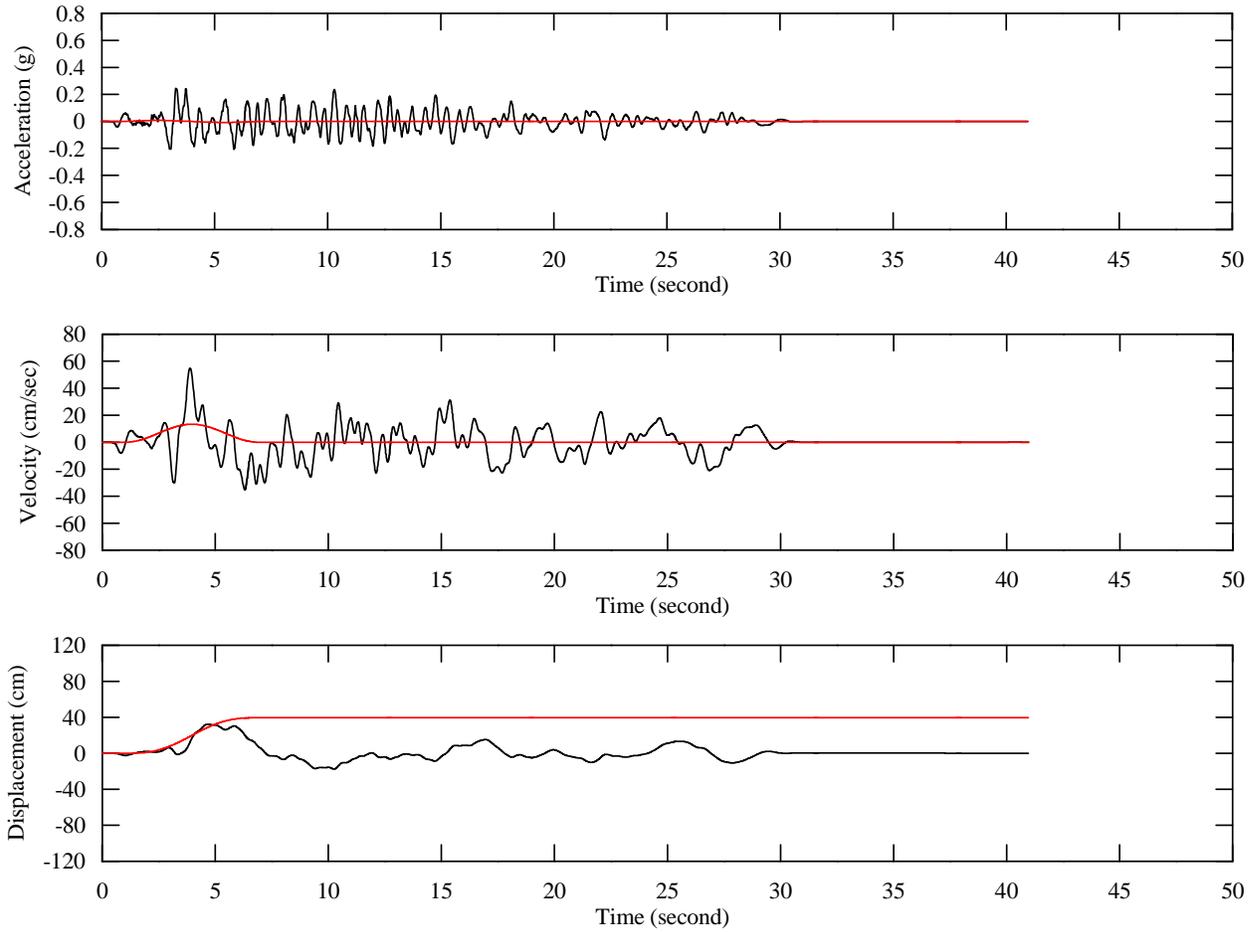


Figure 125: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1999 Kocaeli Earthquake

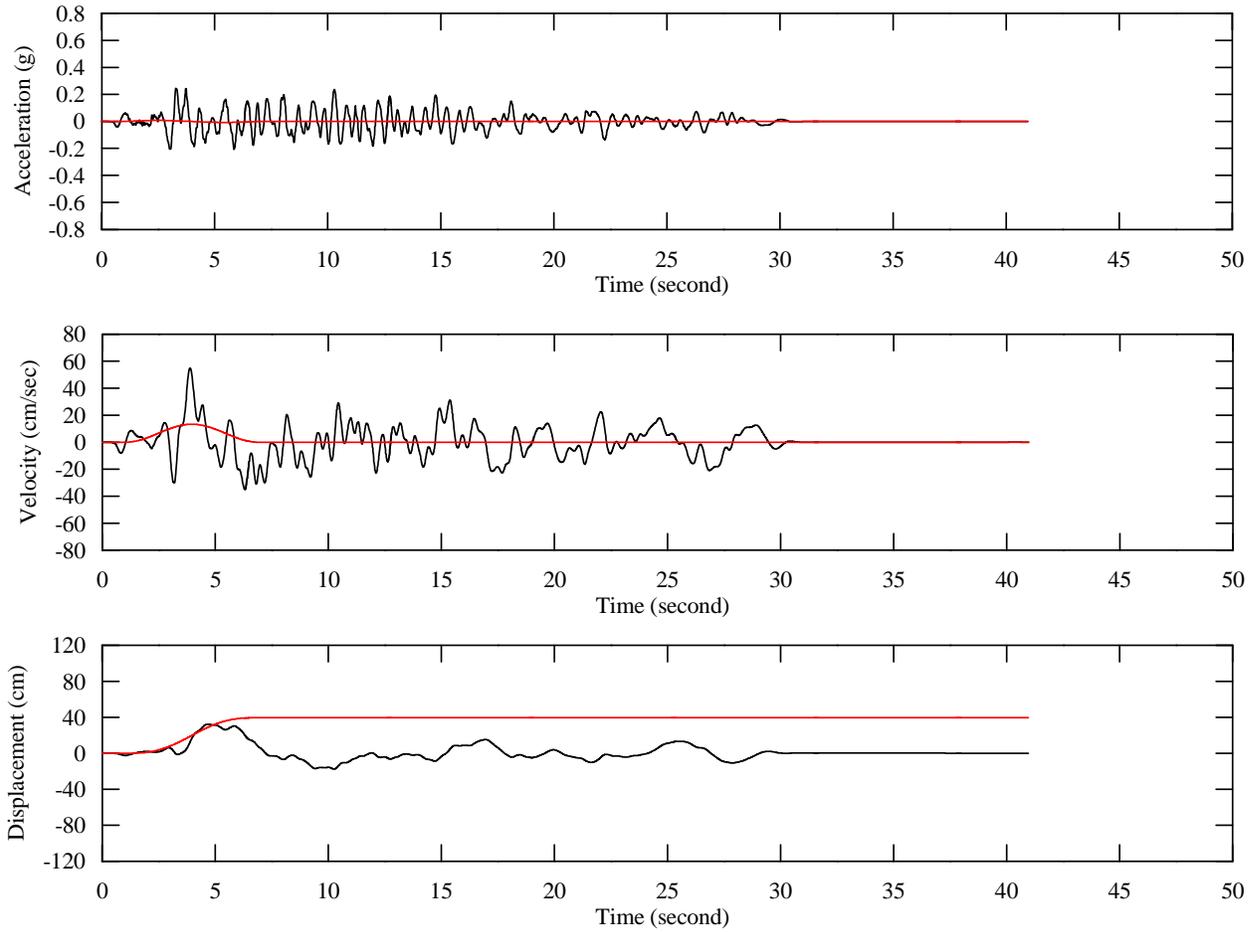


Figure 126: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1999 Kocaeli Earthquake

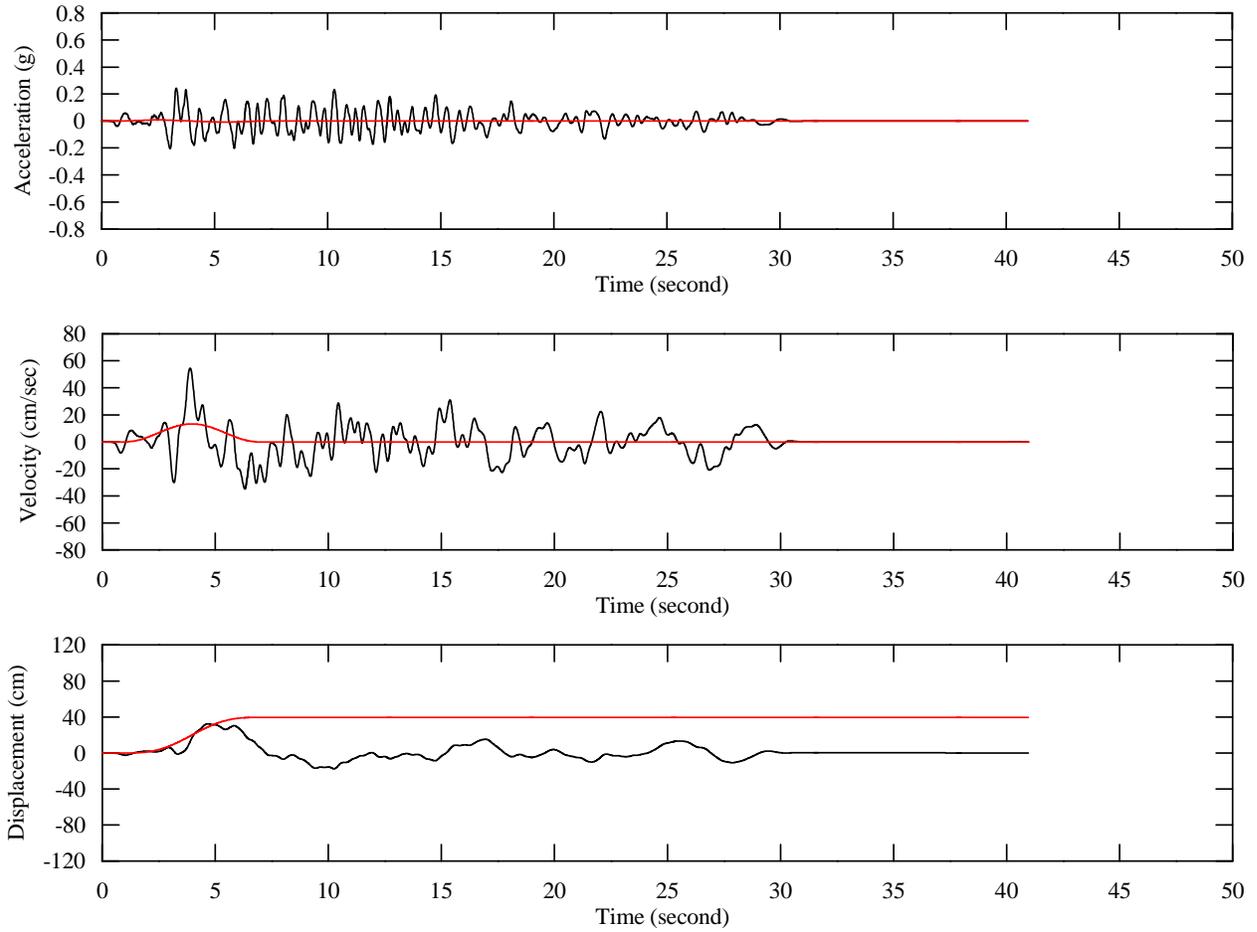


Figure 127: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1999 Kocaeli Earthquake

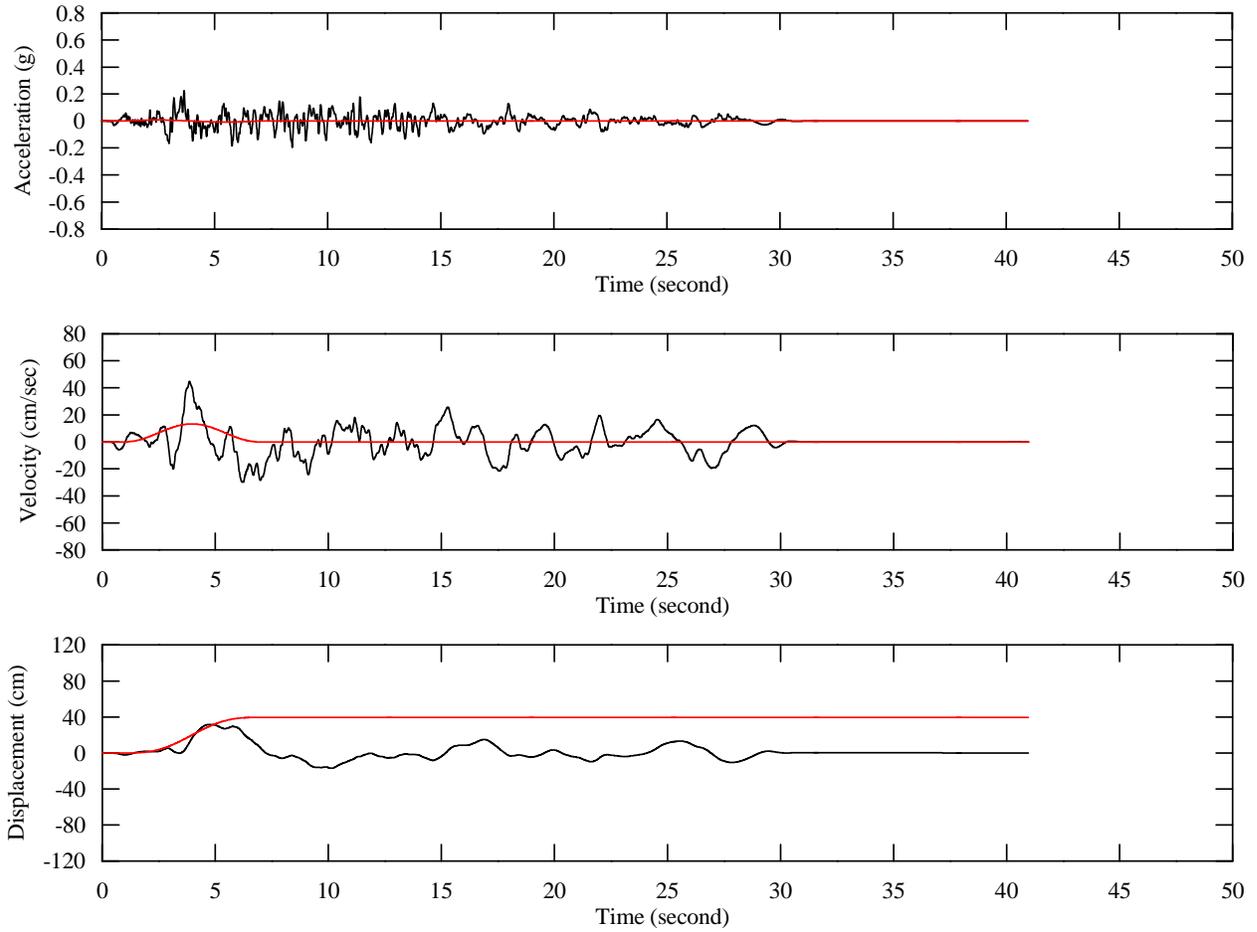


Figure 128: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1999 Kocaeli Earthquake

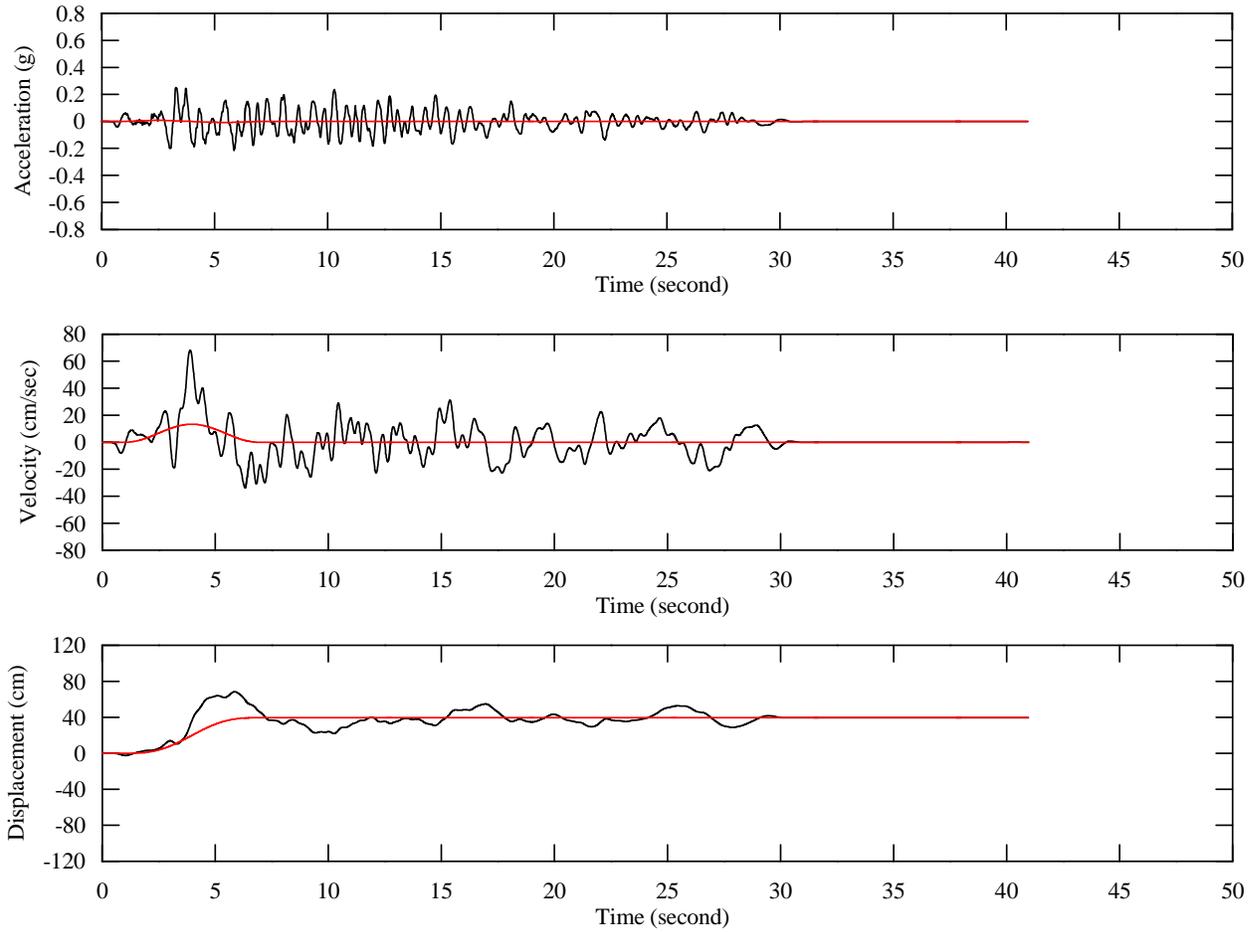


Figure 129: Fault parallel time histories including fling at ground surface, 1999 Kocaeli Earthquake

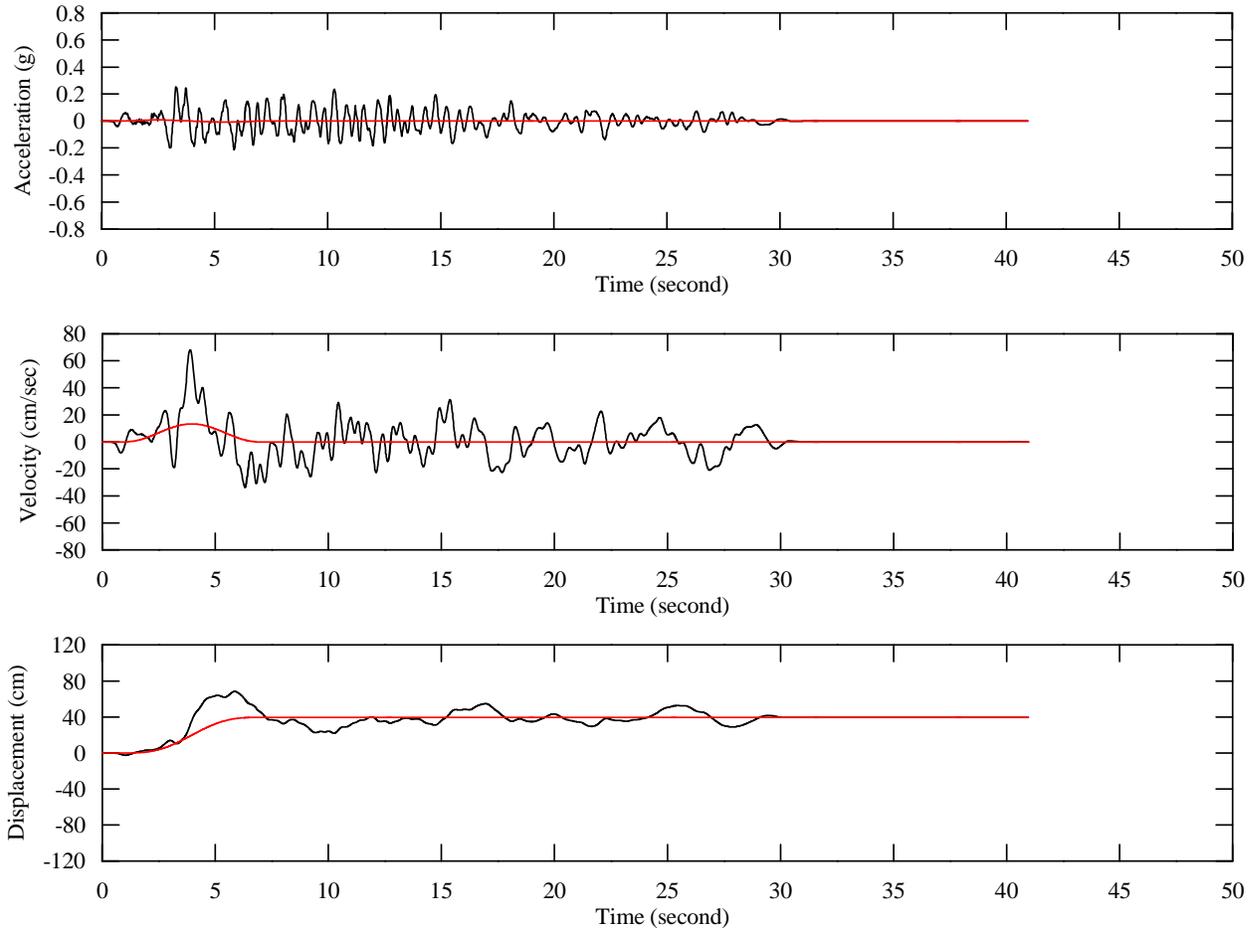


Figure 130: Fault parallel time histories including fling at crown of the tunnel, 1999 Kocaeli Earthquake

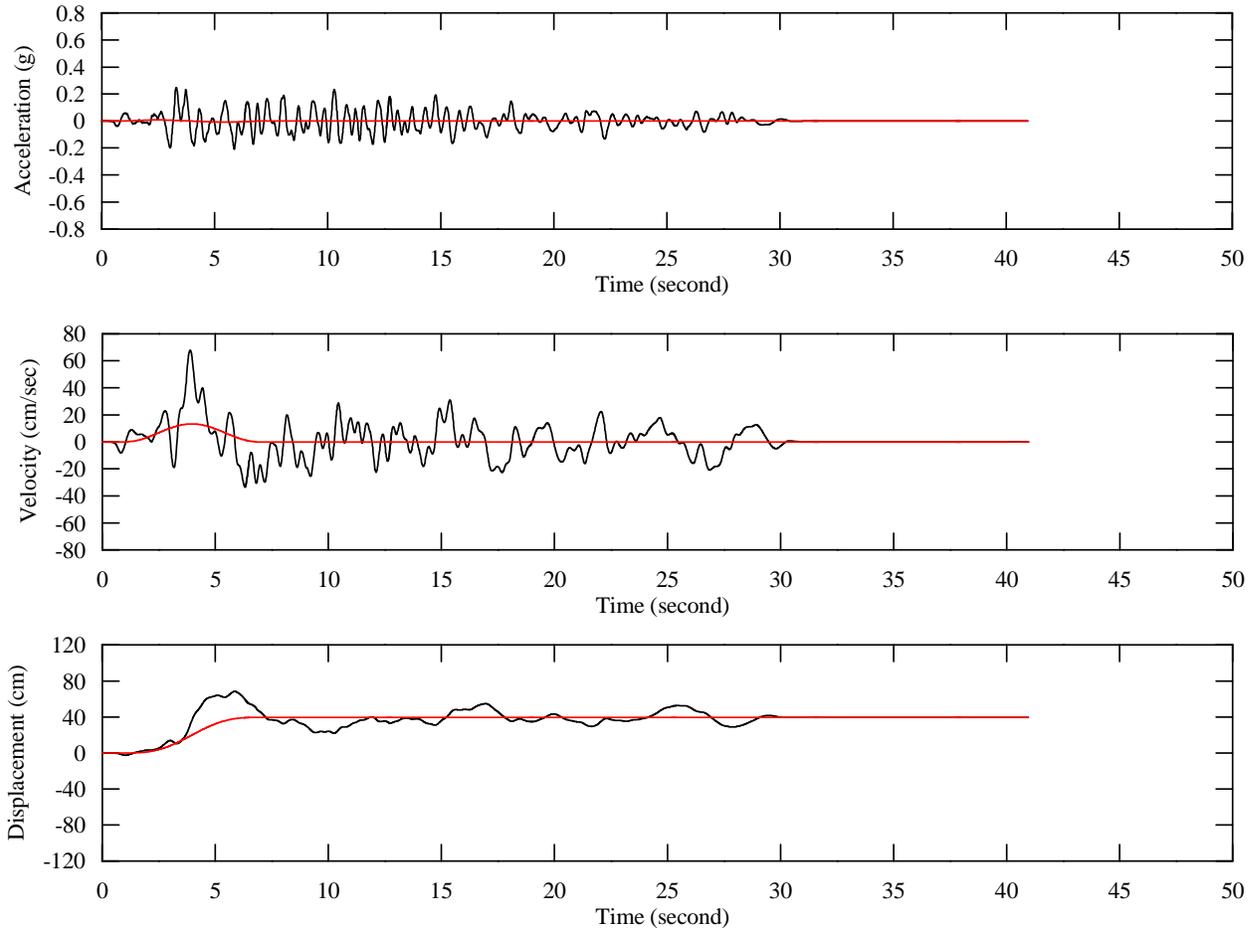


Figure 131: Fault parallel time histories including fling at top of side wall, 1999 Kocaeli Earthquake

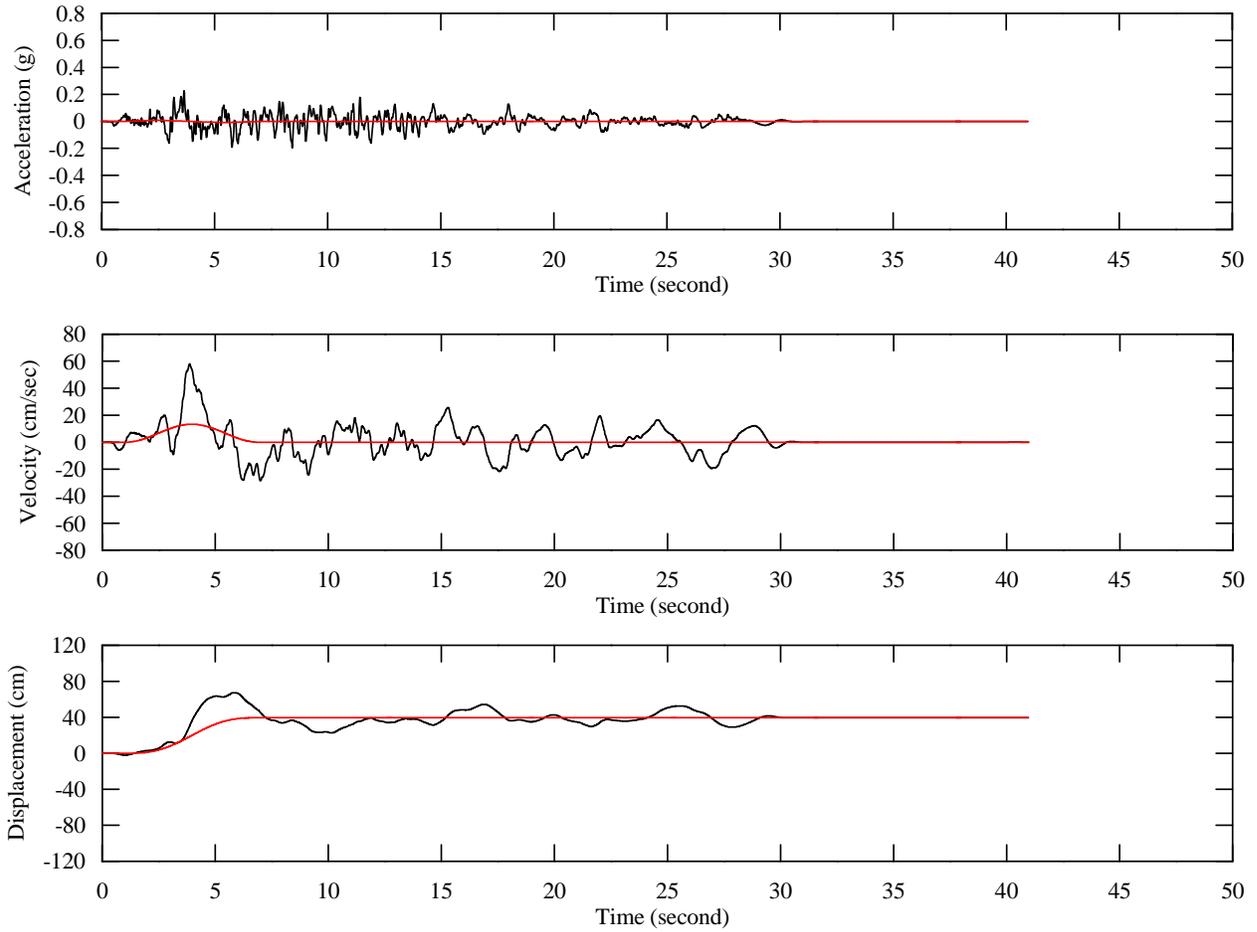


Figure 132: Fault parallel time histories including fling at invert of the tunnel, 1999 Kocaeli Earthquake

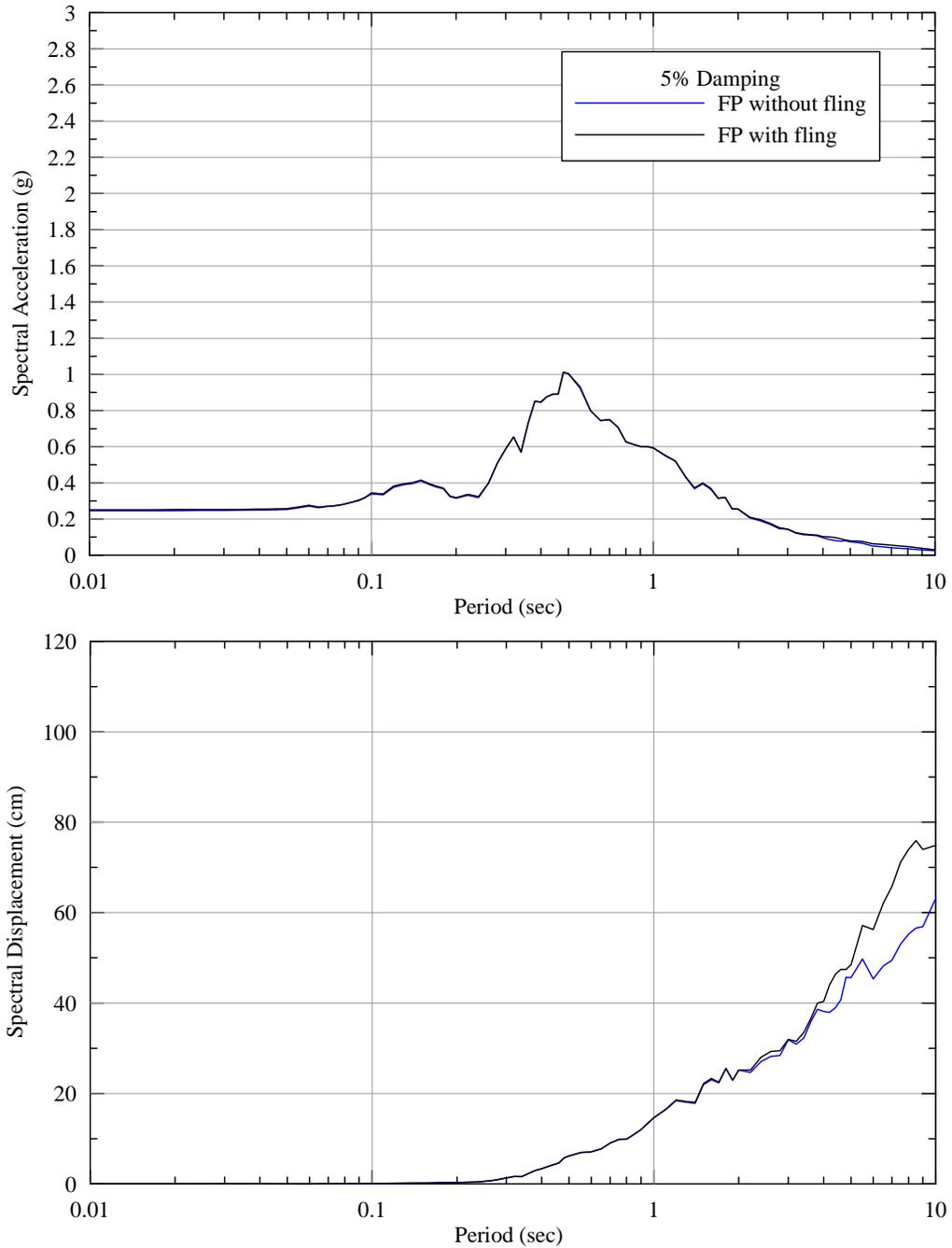


Figure 133: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1999 Kocaeli Earthquake

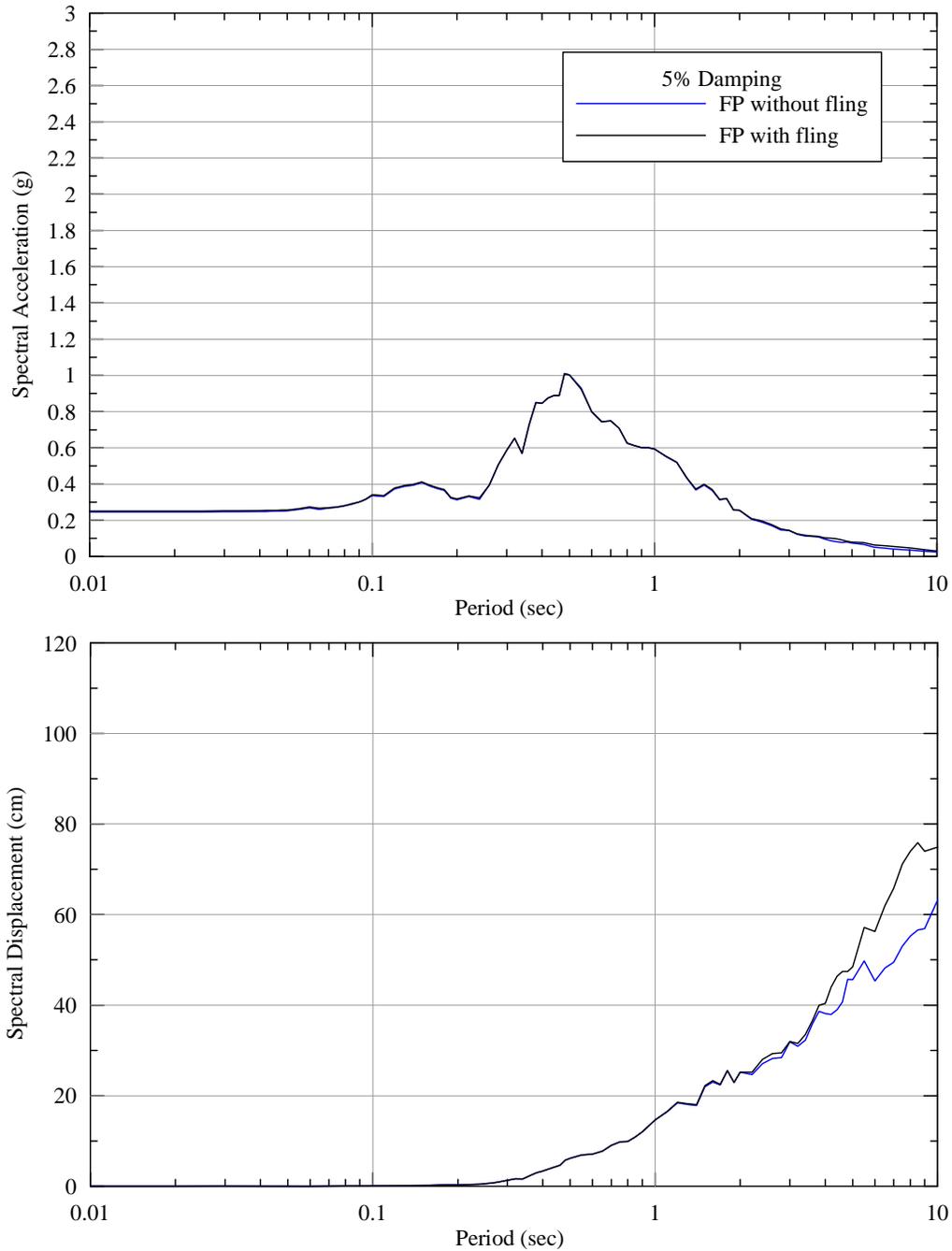


Figure 134: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1999 Kocaeli Earthquake

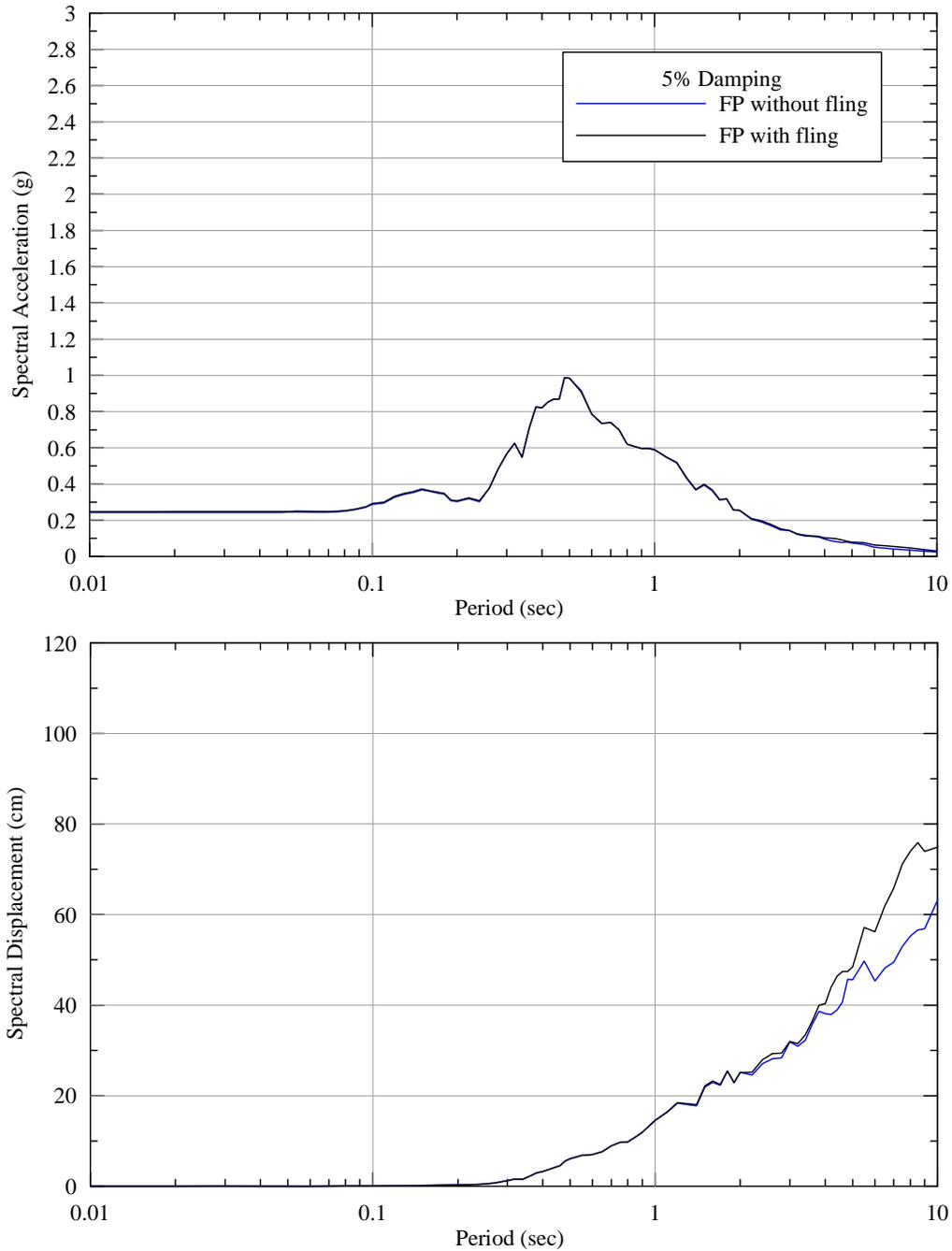


Figure 135: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1999 Kocaeli Earthquake

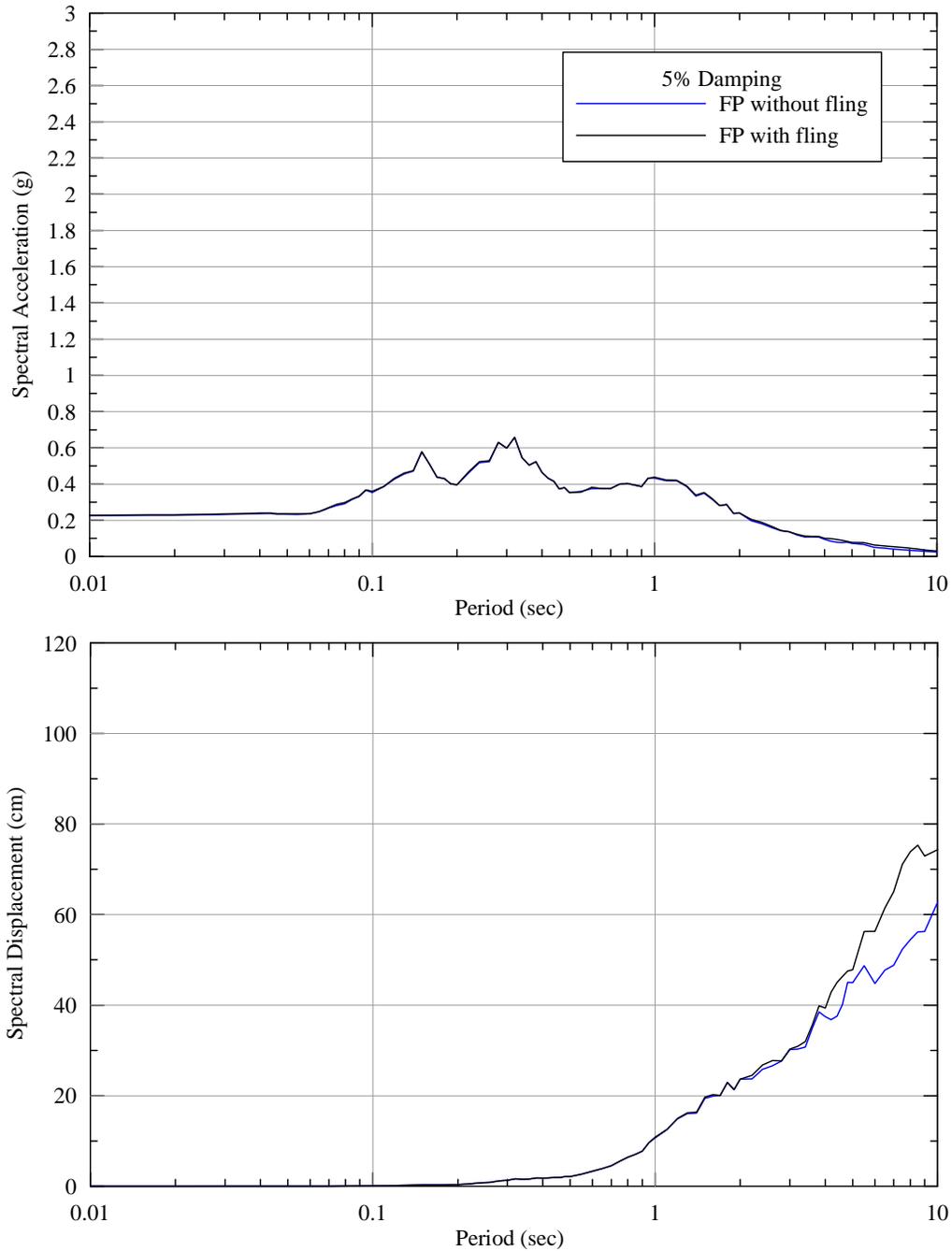


Figure 136: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1999 Kocaeli Earthquake

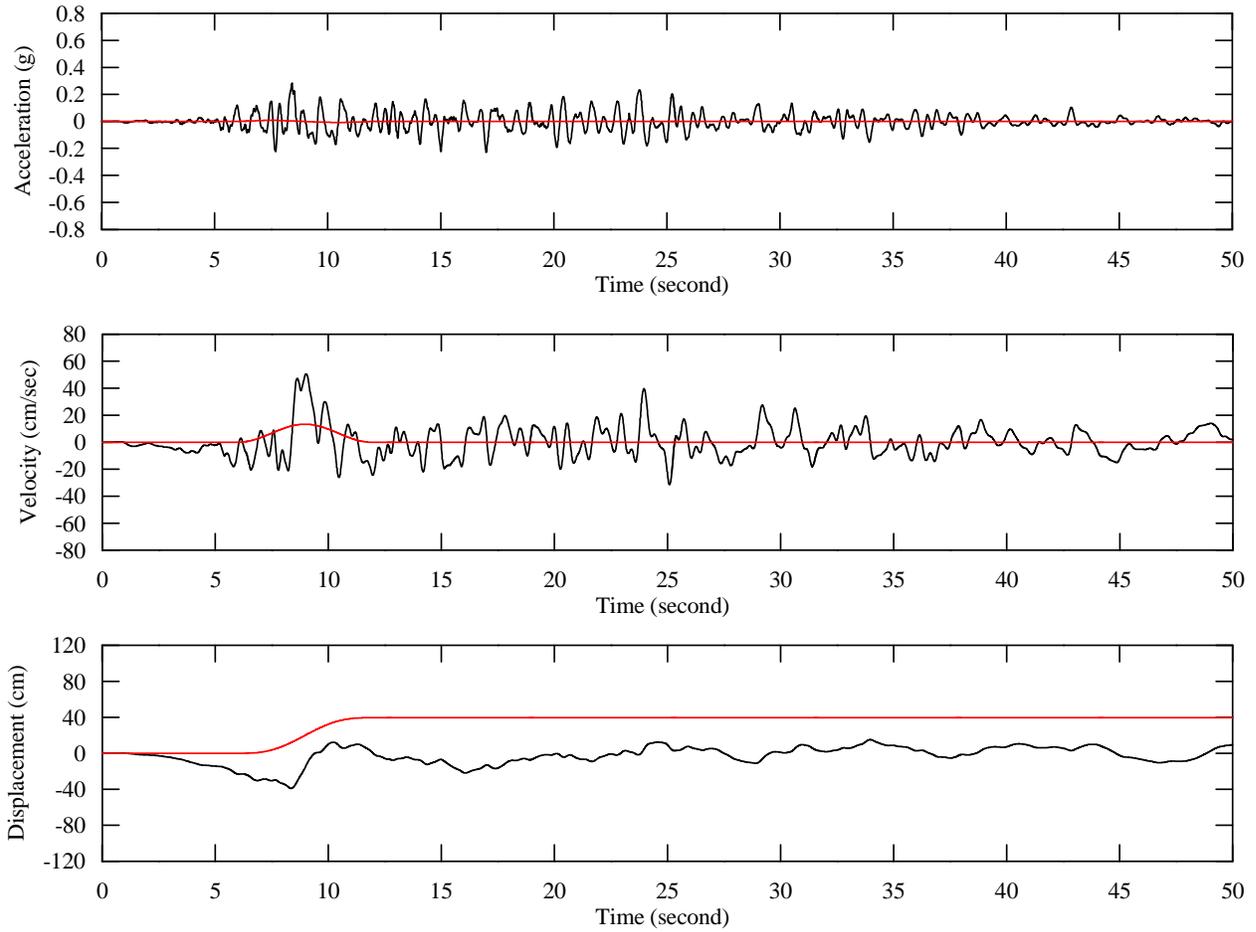


Figure 137: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

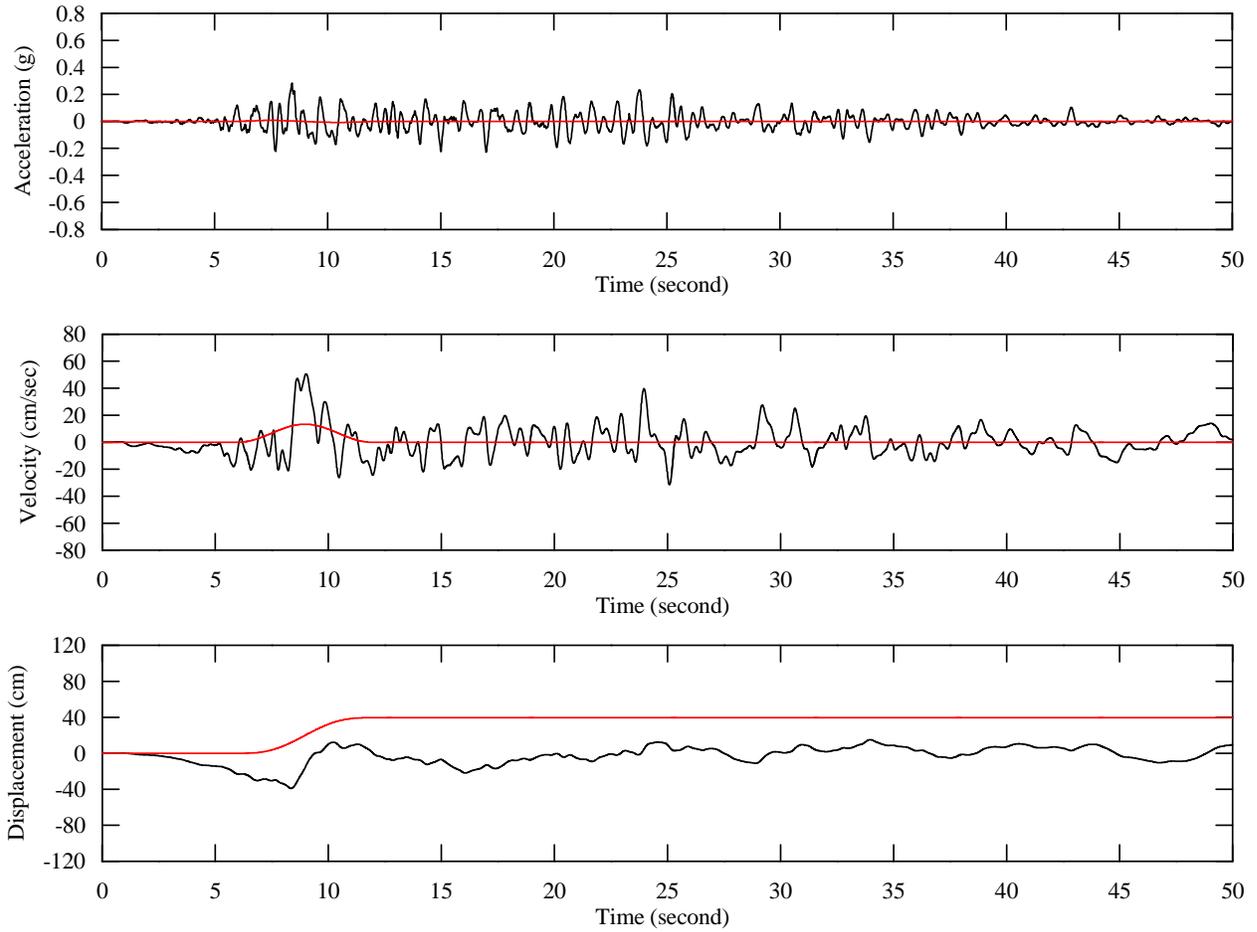


Figure 138: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

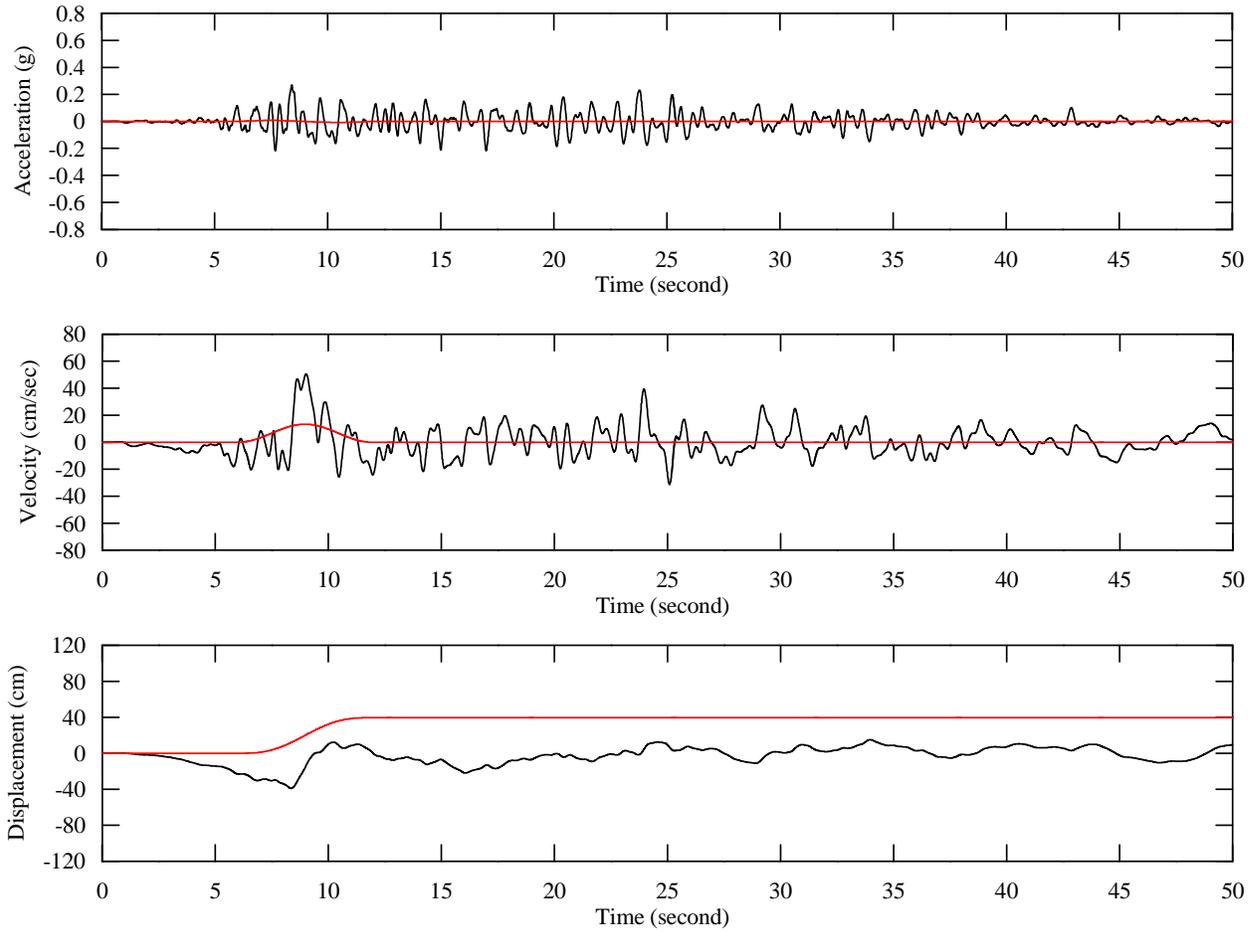


Figure 139: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

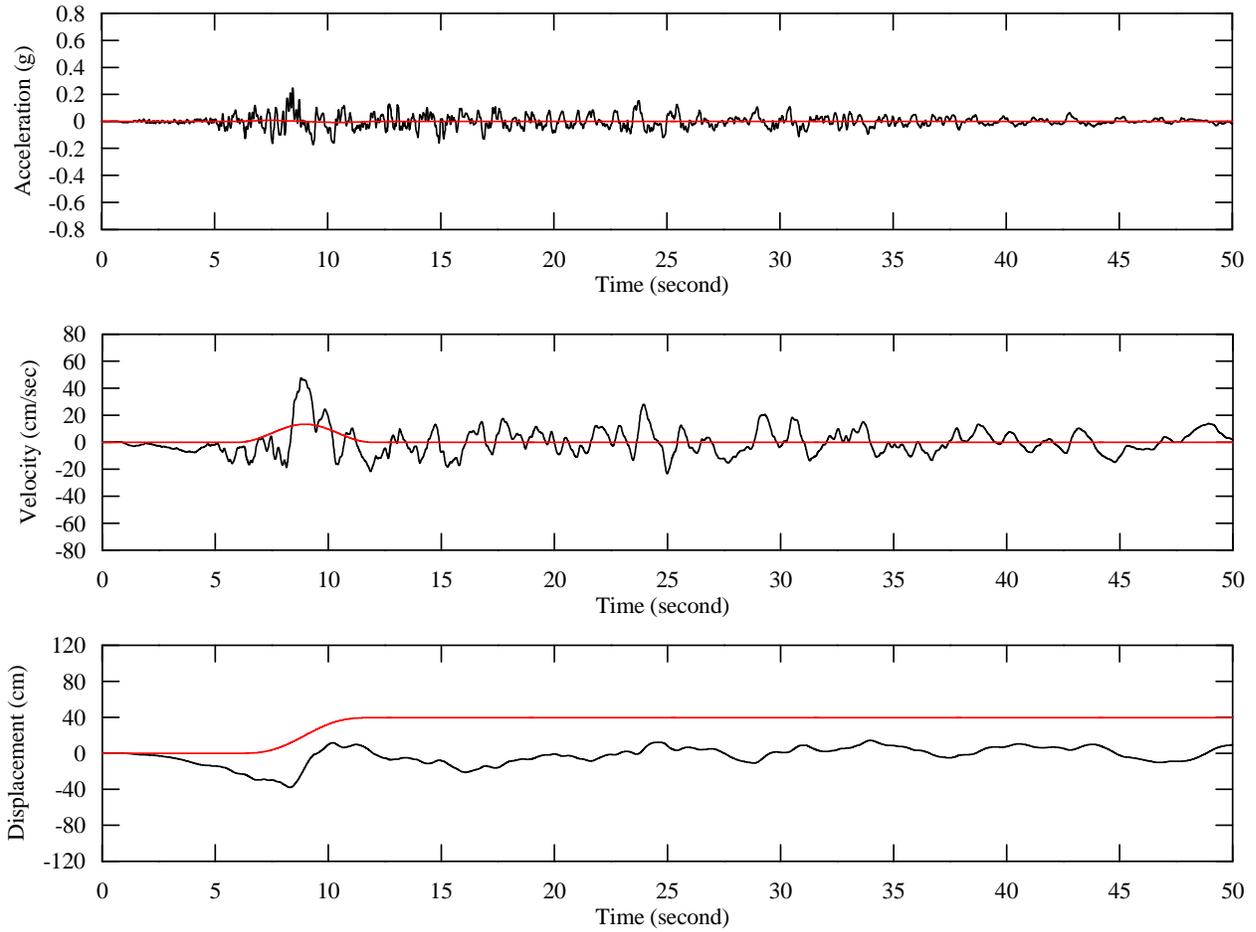


Figure 140: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

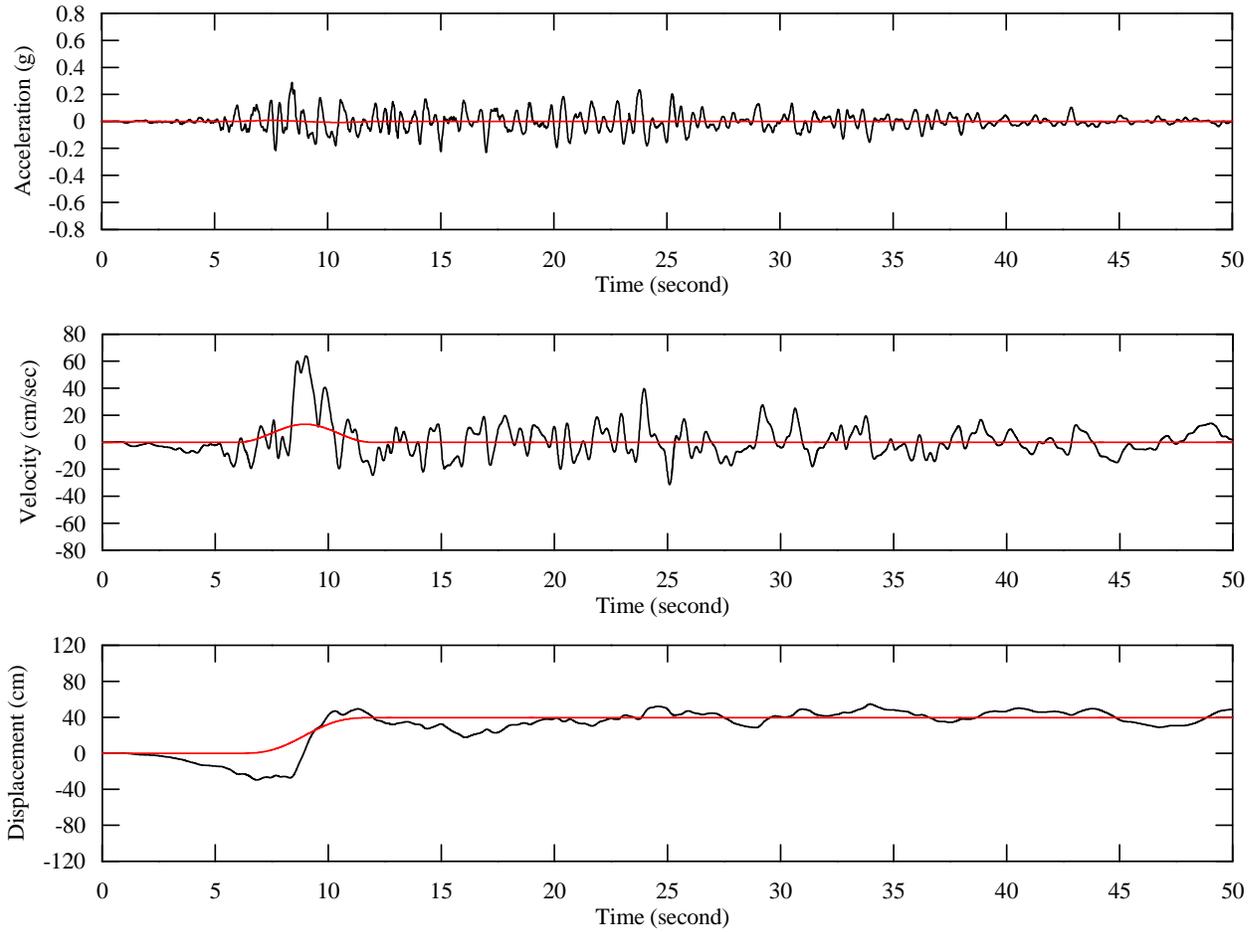


Figure 141: Fault parallel time histories including fling at ground surface, 1999 Chi-Chi Earthquake

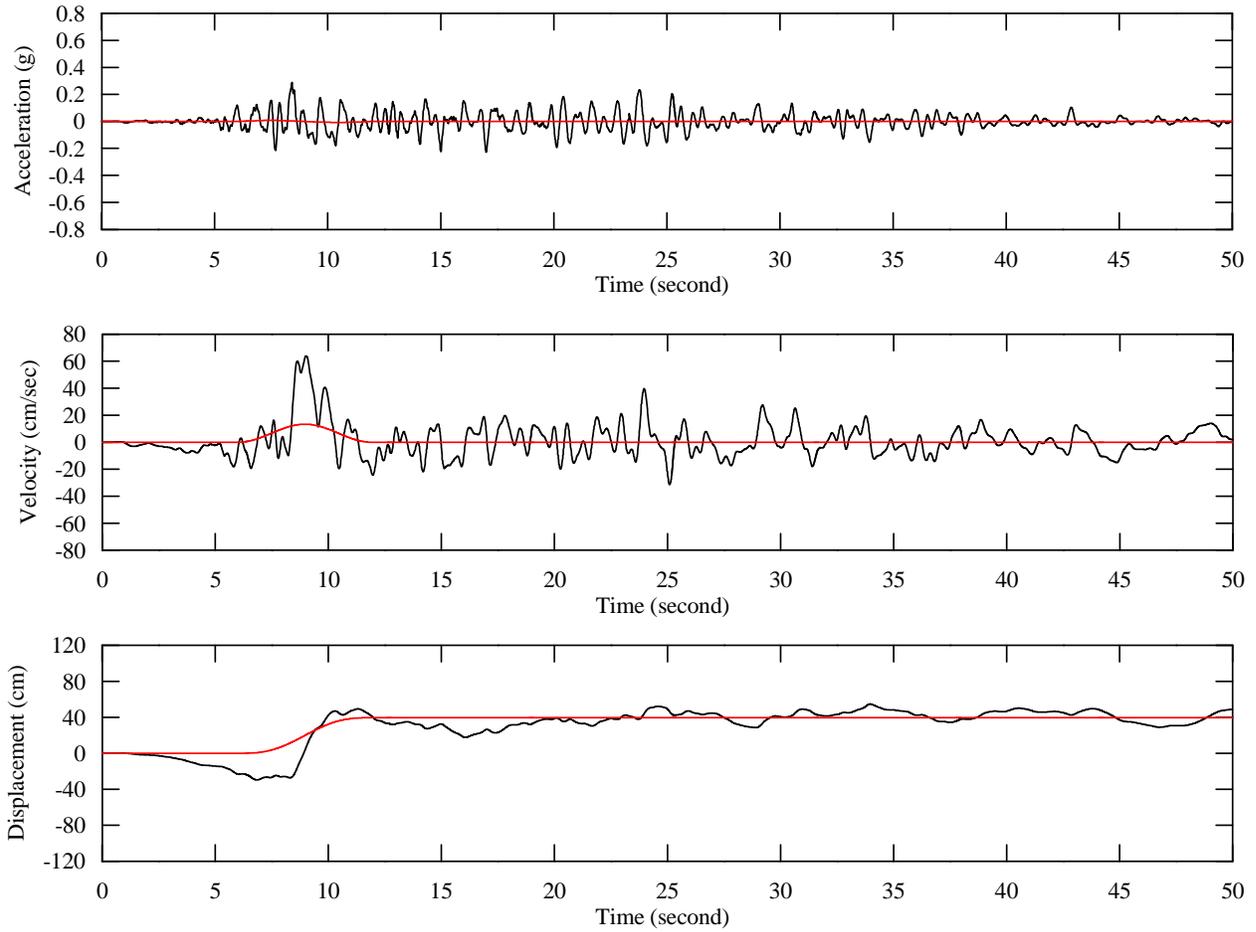


Figure 142: Fault parallel time histories including fling at crown of the tunnel, 1999 Chi-Chi Earthquake

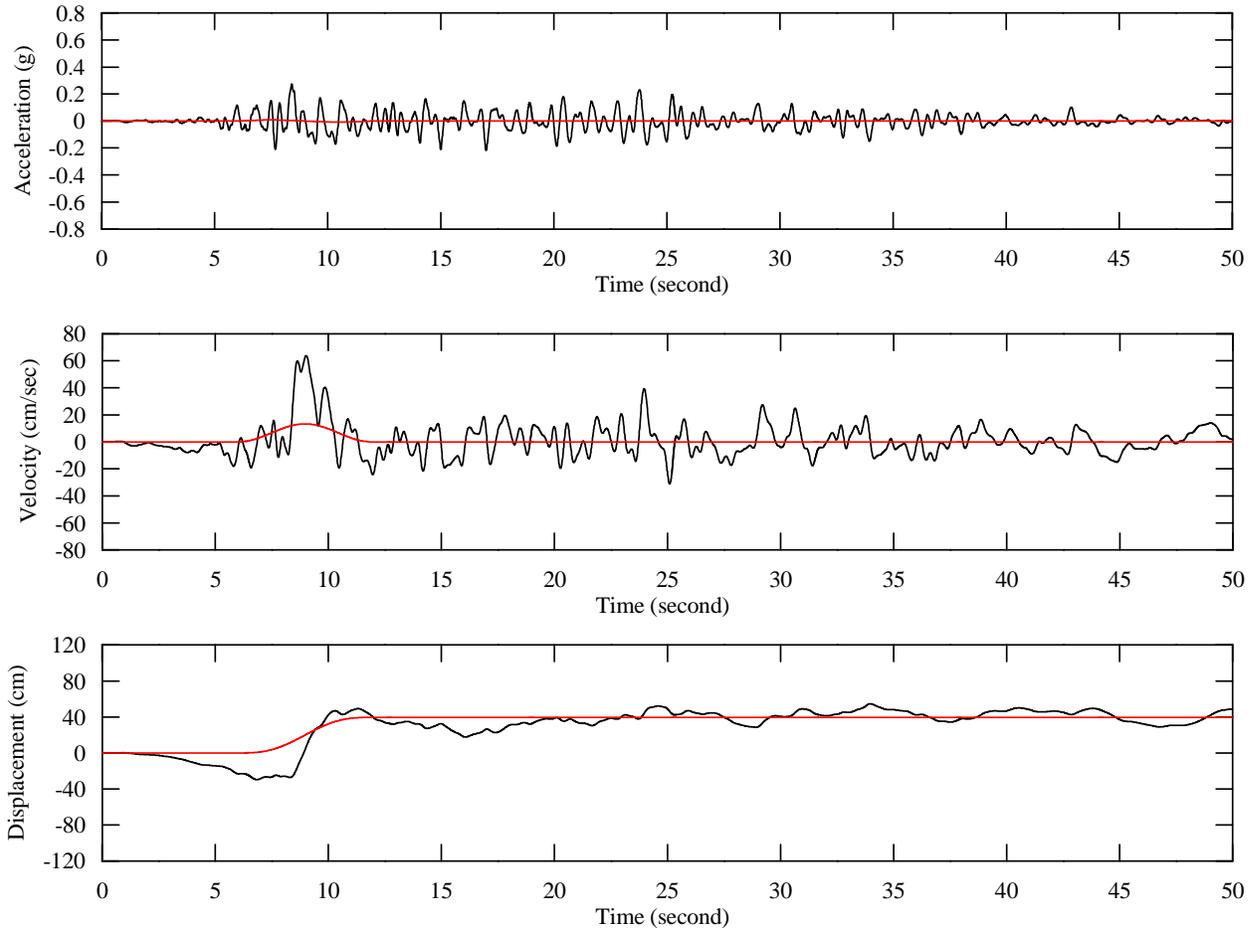


Figure 143: Fault parallel time histories including fling at top of side wall, 1999 Chi-Chi Earthquake

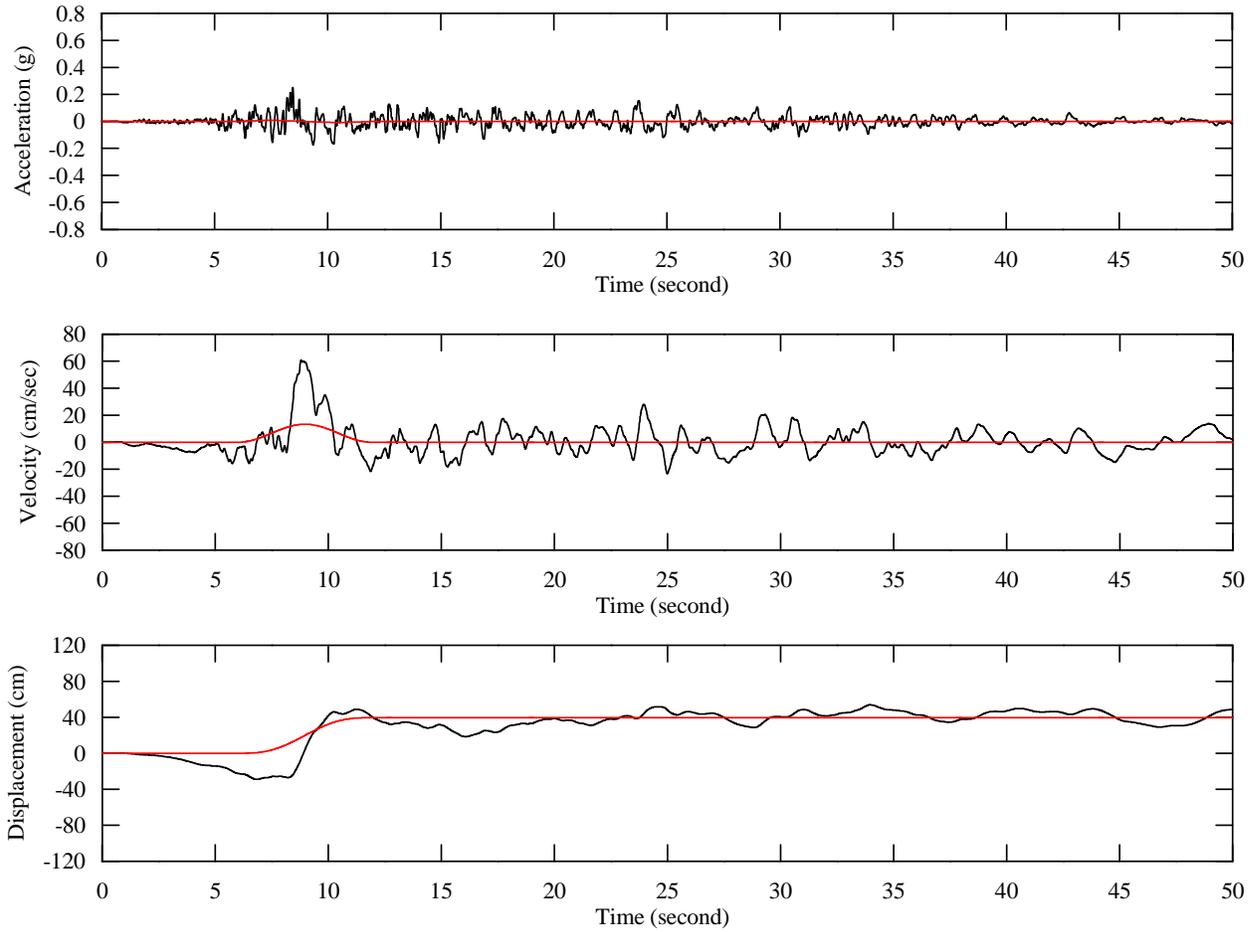


Figure 144: Fault parallel time histories including fling at invert of the tunnel, 1999 Chi-Chi Earthquake

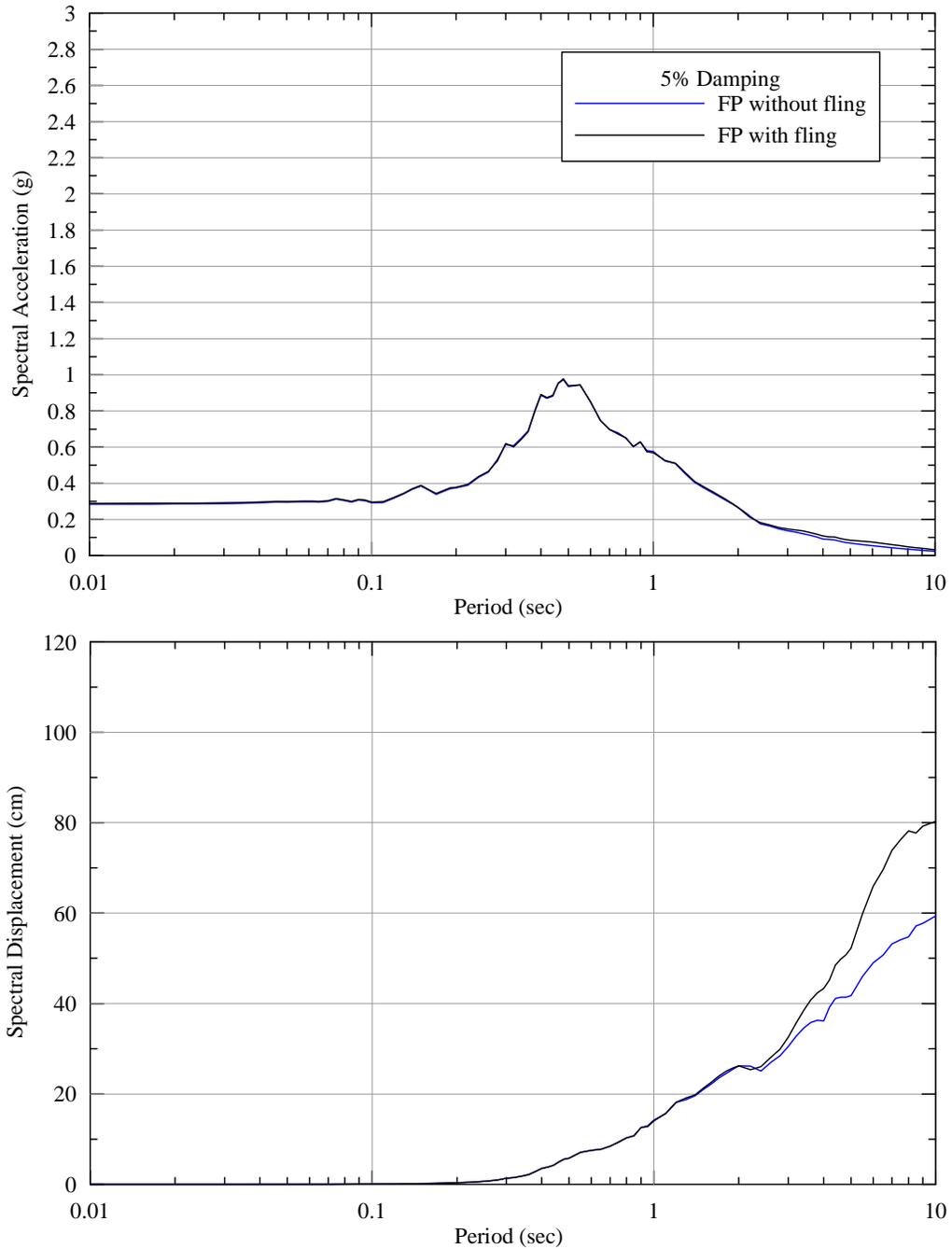


Figure 145: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1999 Chi-Chi Earthquake

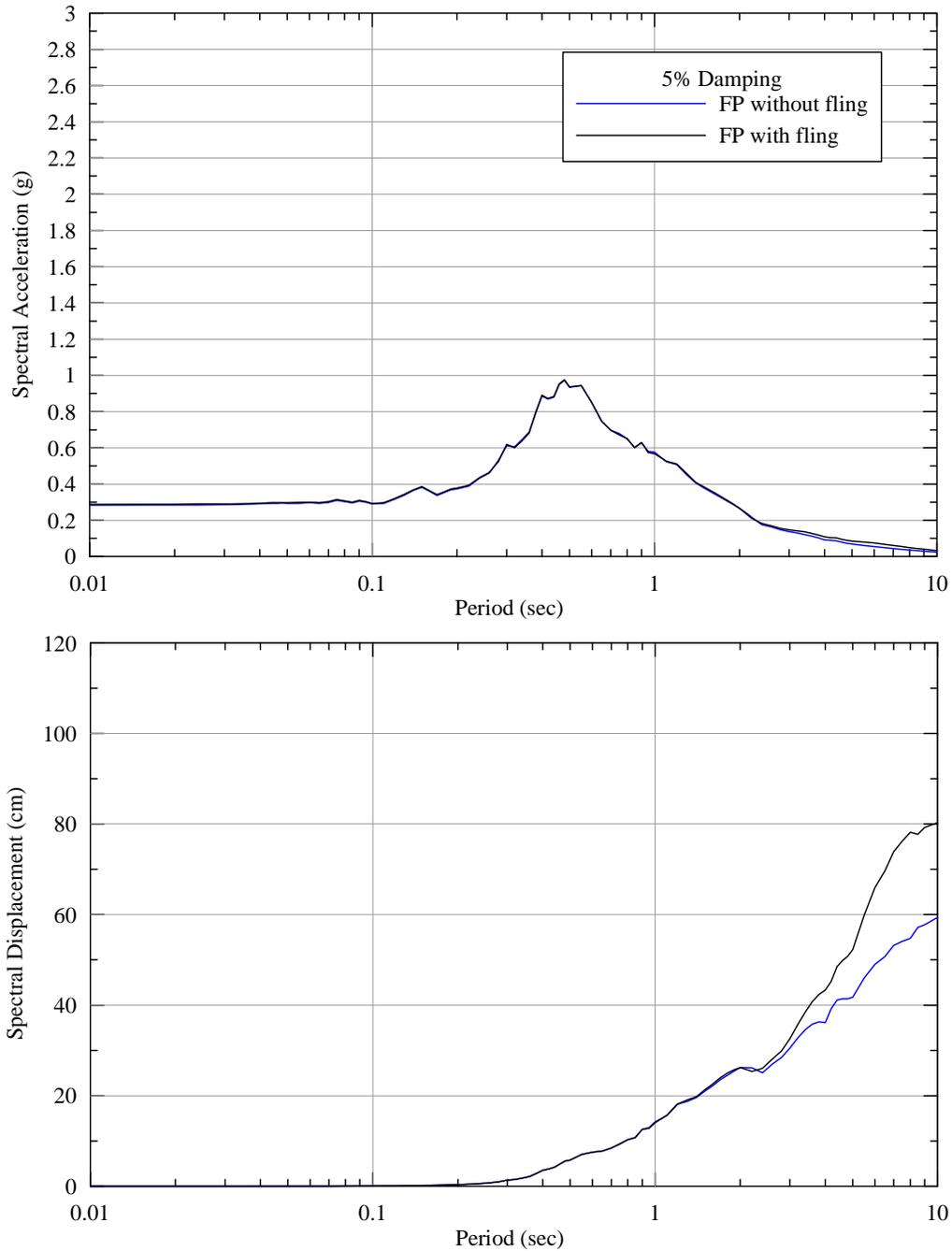


Figure 146: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1999 Chi-Chi Earthquake

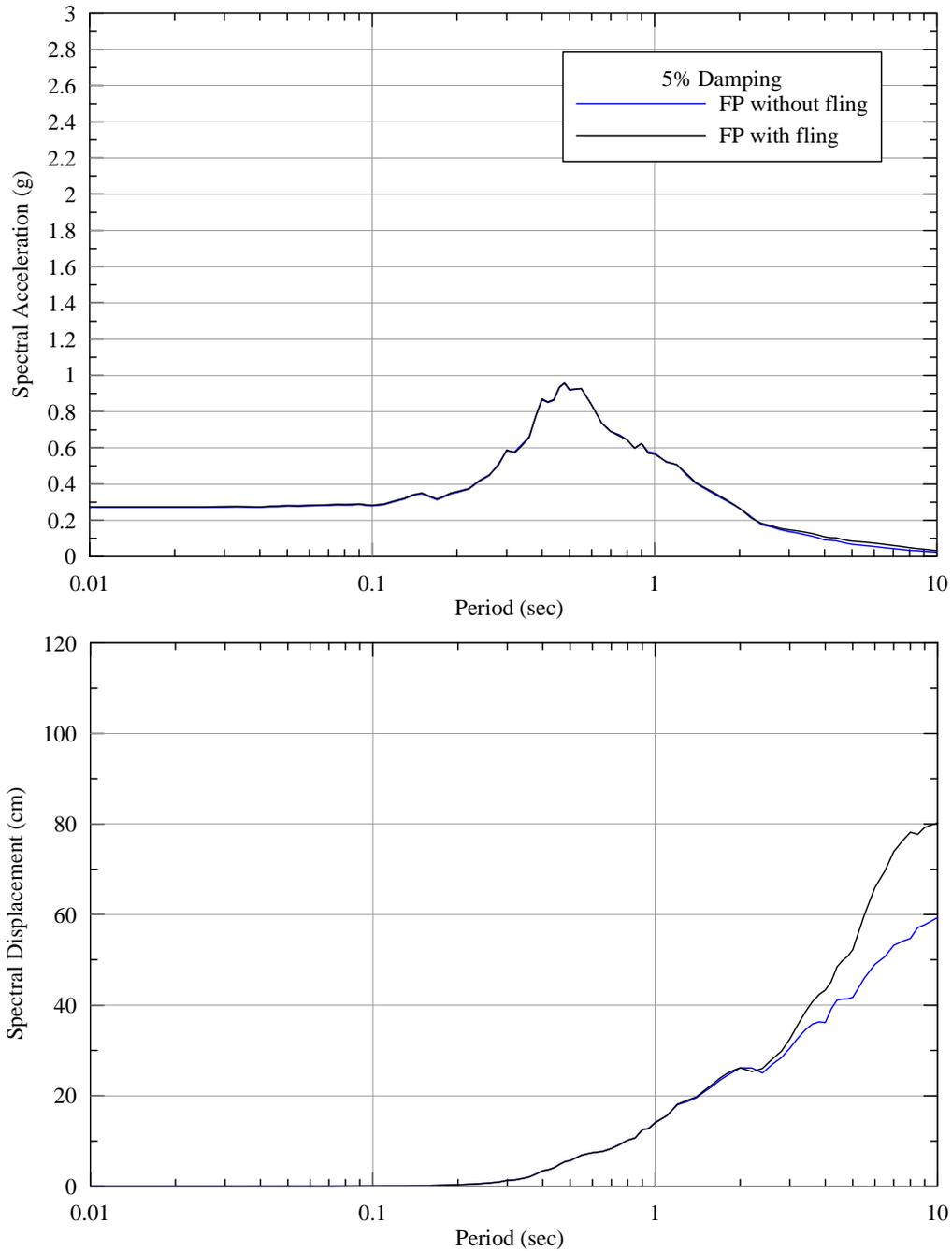


Figure 147: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1999 Chi-Chi Earthquake

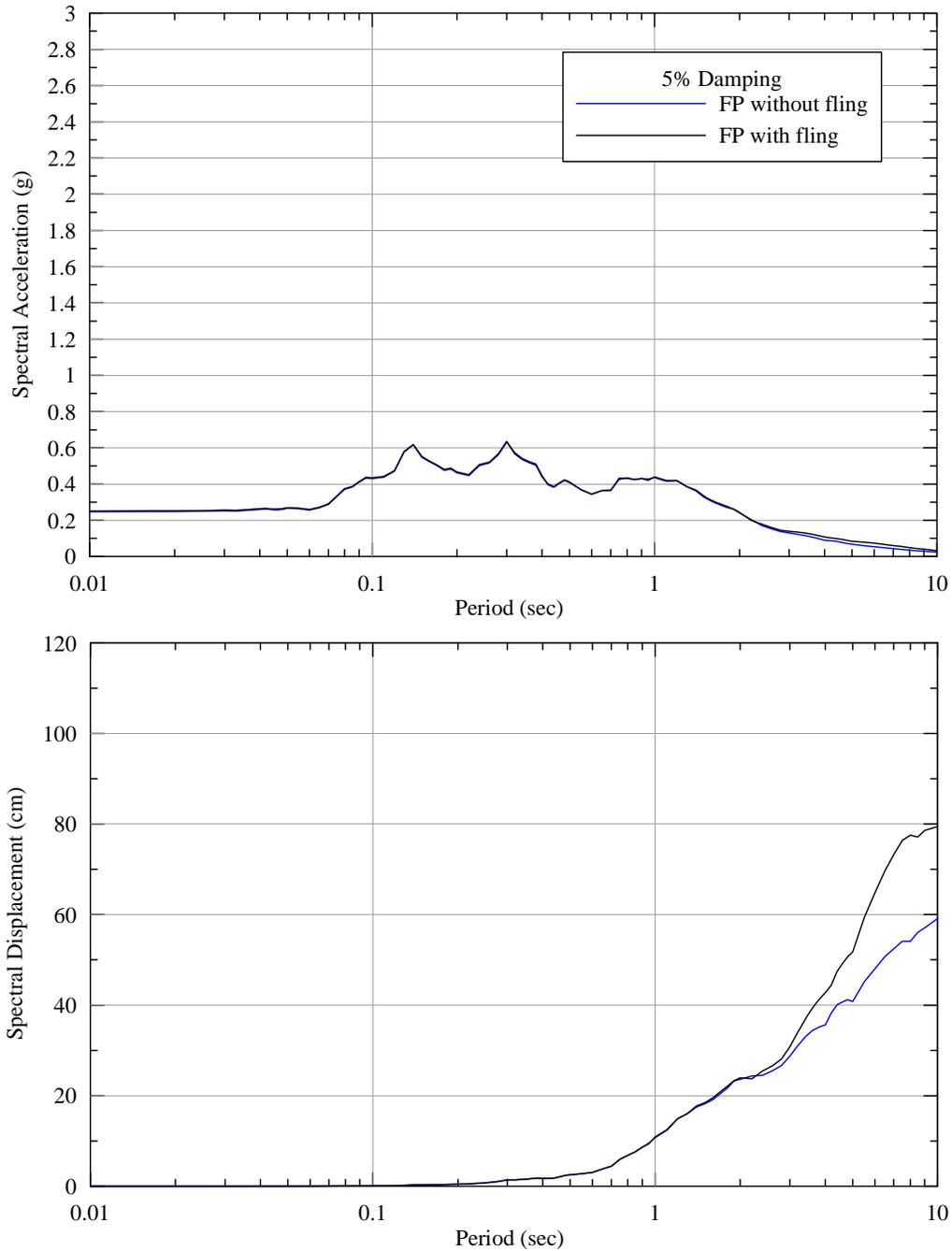


Figure 148: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1999 Chi-Chi Earthquake

SOUTH MAIN POST TUNNEL (SHALLOW) PROFILE

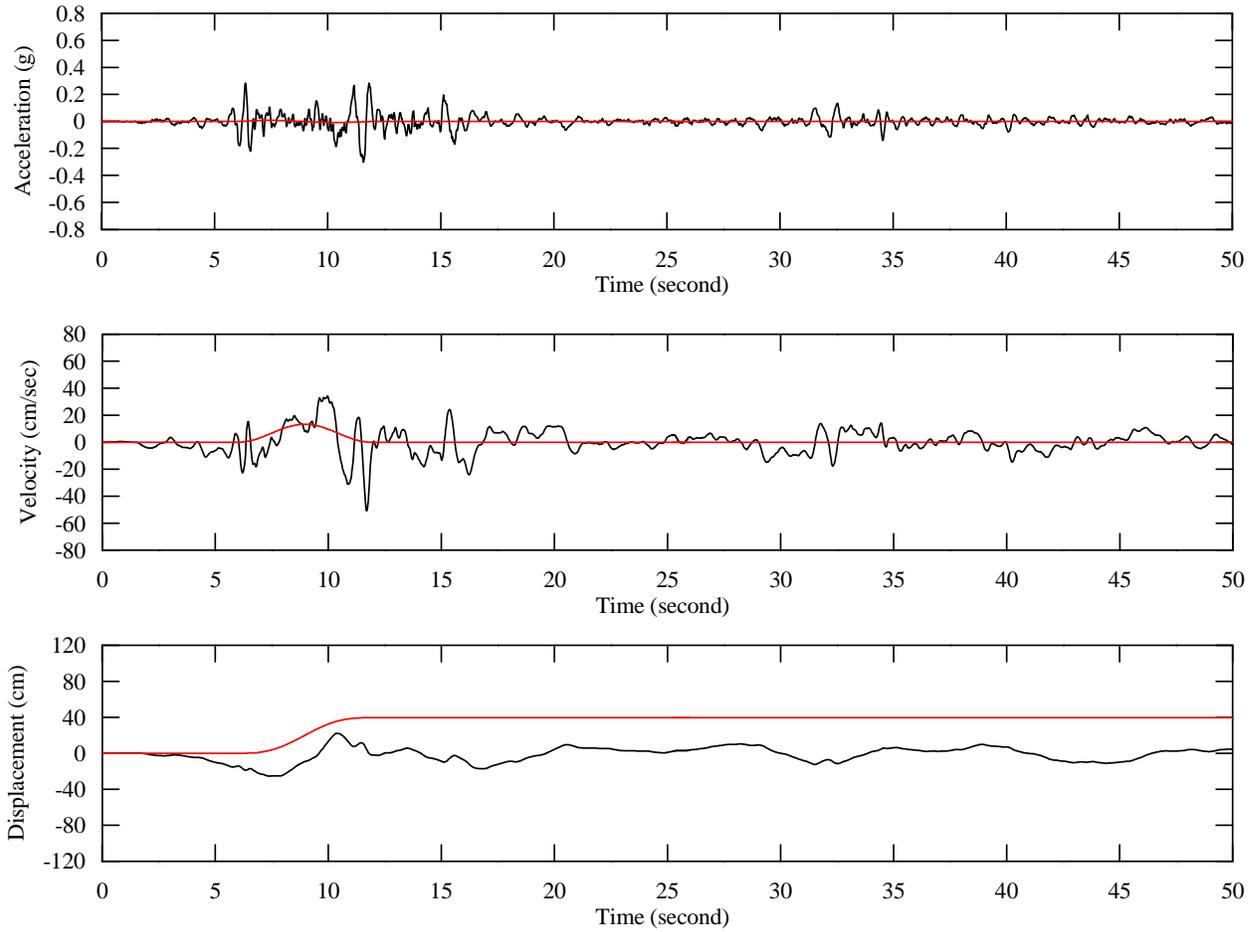


Figure 149: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1990 Manjil Earthquake

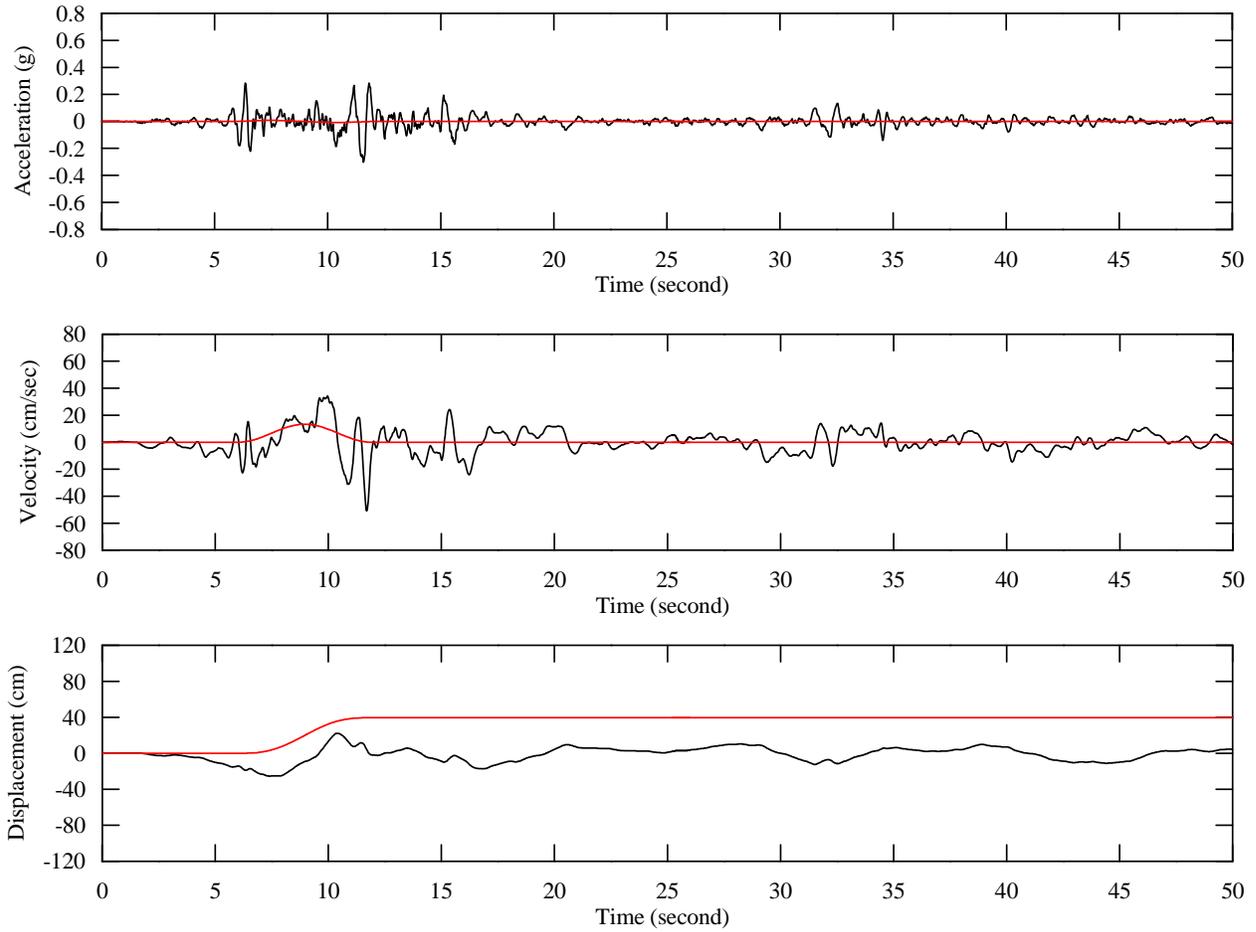


Figure 150: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1990 Manjil Earthquake

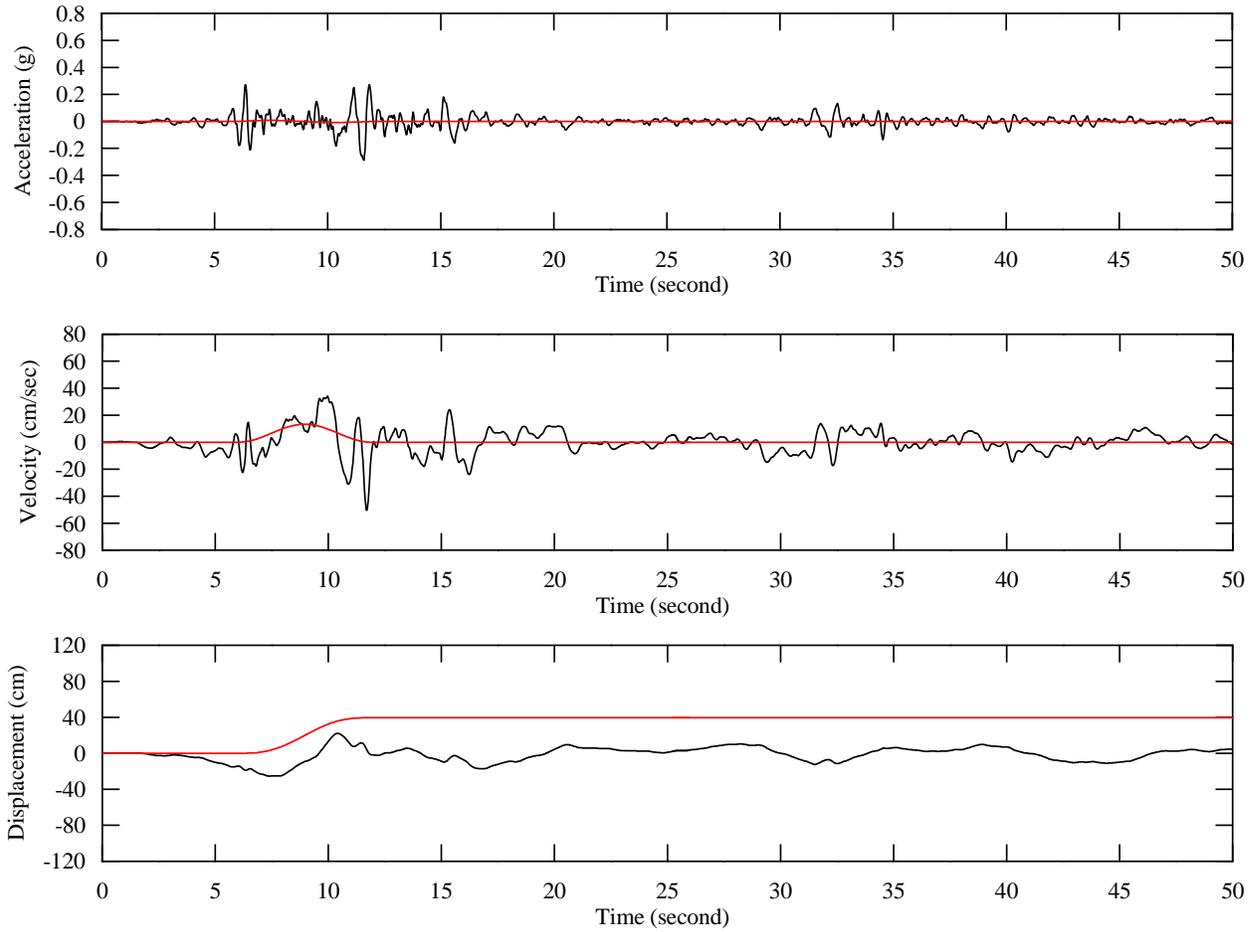


Figure 151: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1990 Manjil Earthquake

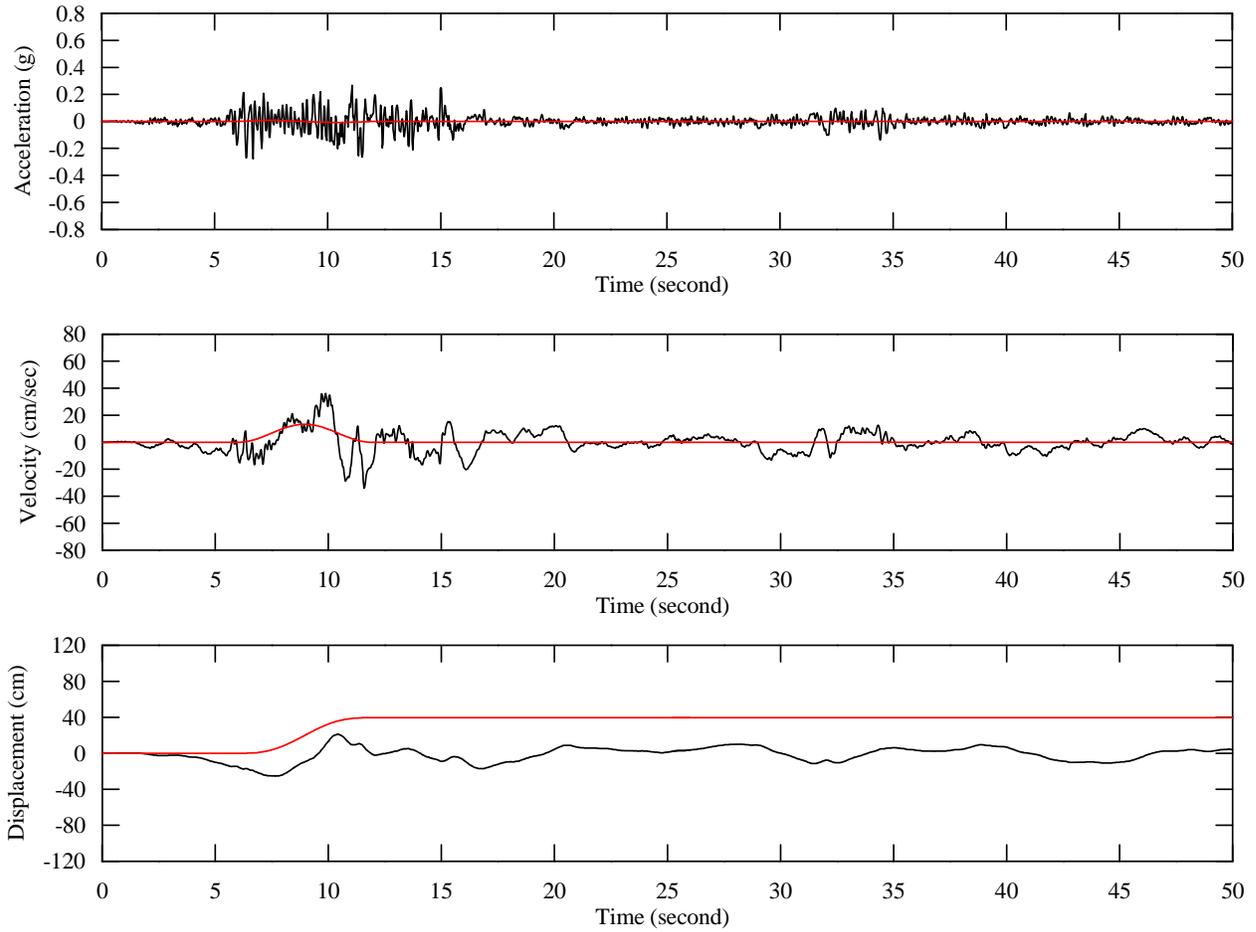


Figure 152: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1990 Manjil Earthquake

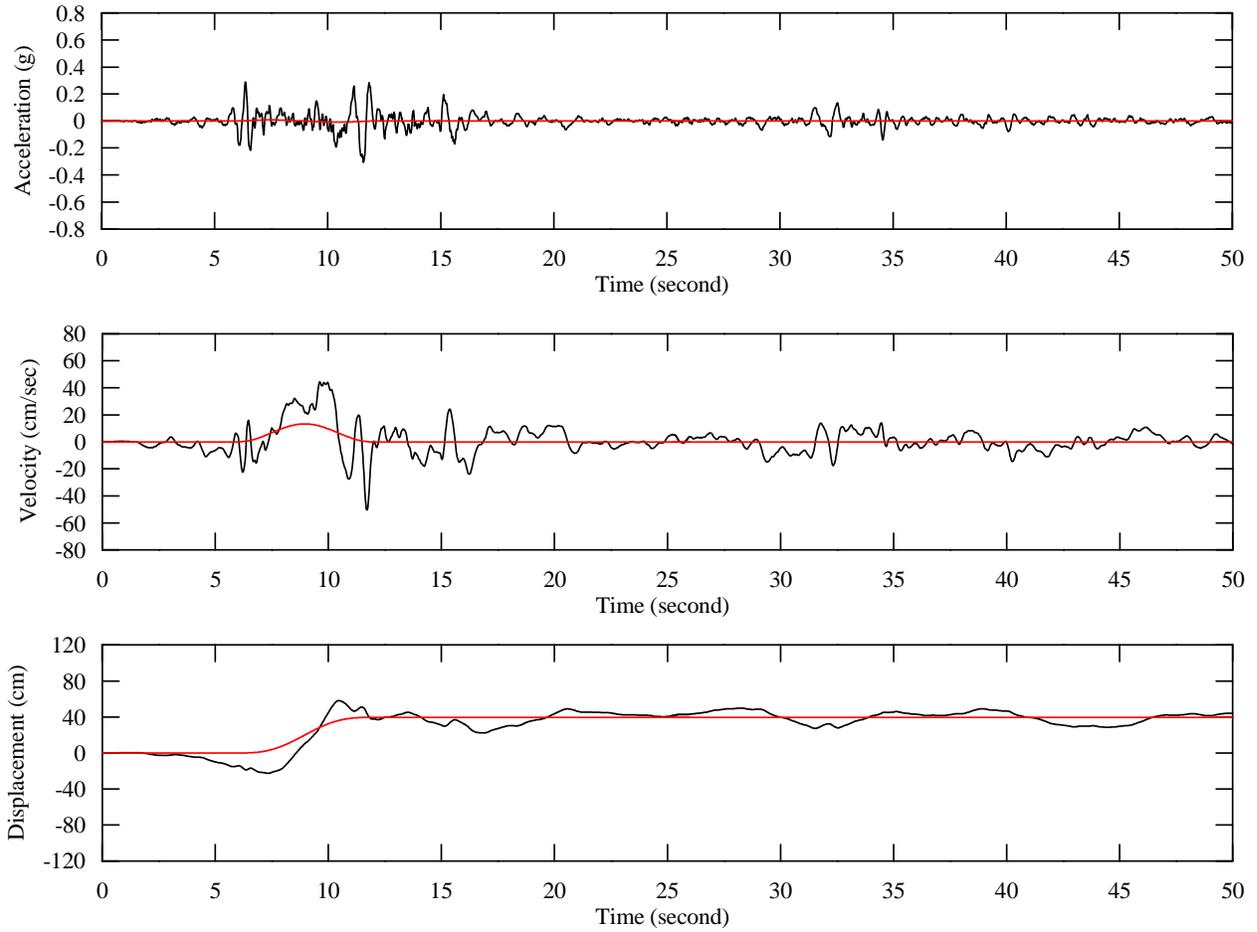


Figure 153: Fault parallel time histories including fling at ground surface, 1990 Manjil Earthquake

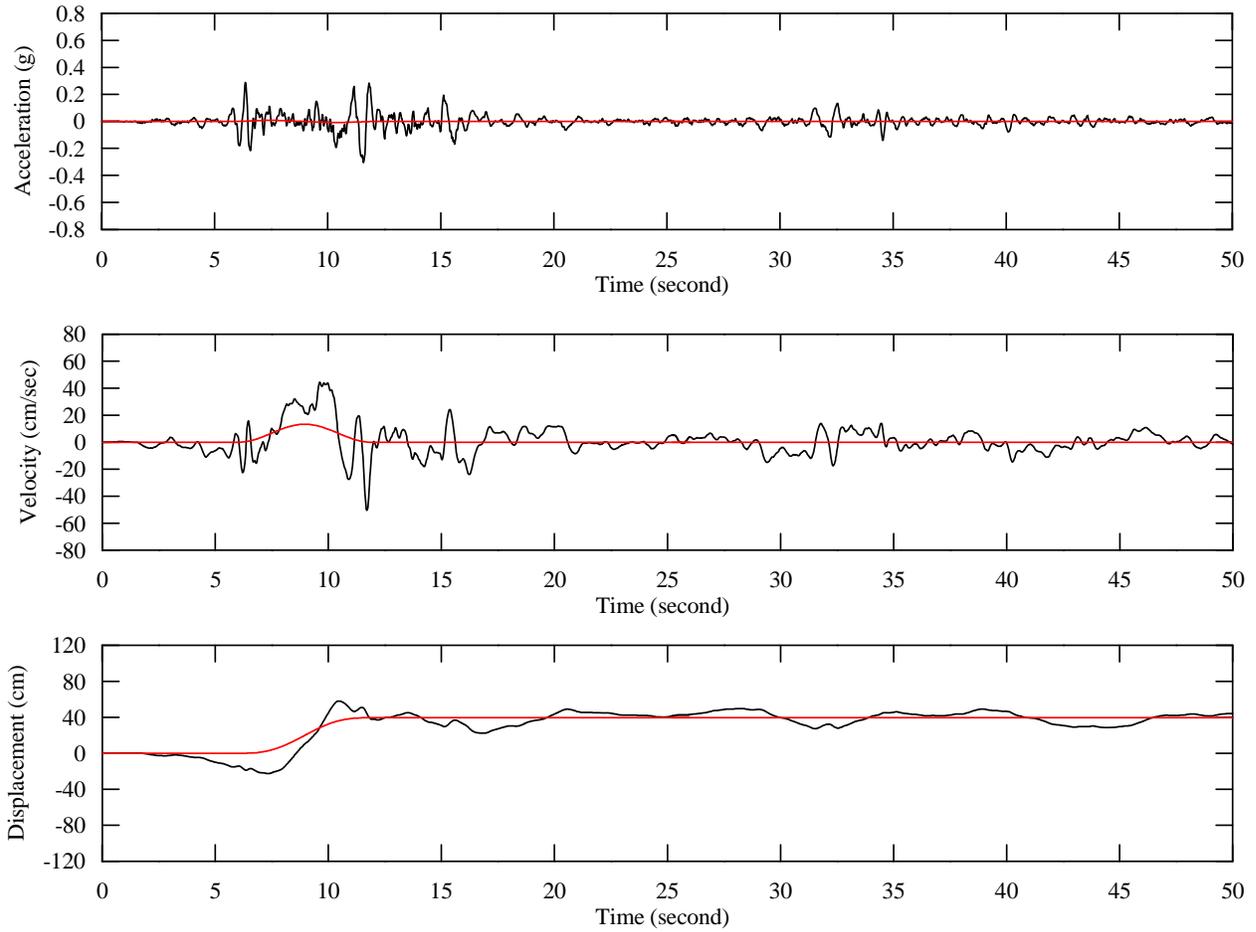


Figure 154: Fault parallel time histories including fling at crown of the tunnel, 1990 Manjil Earthquake

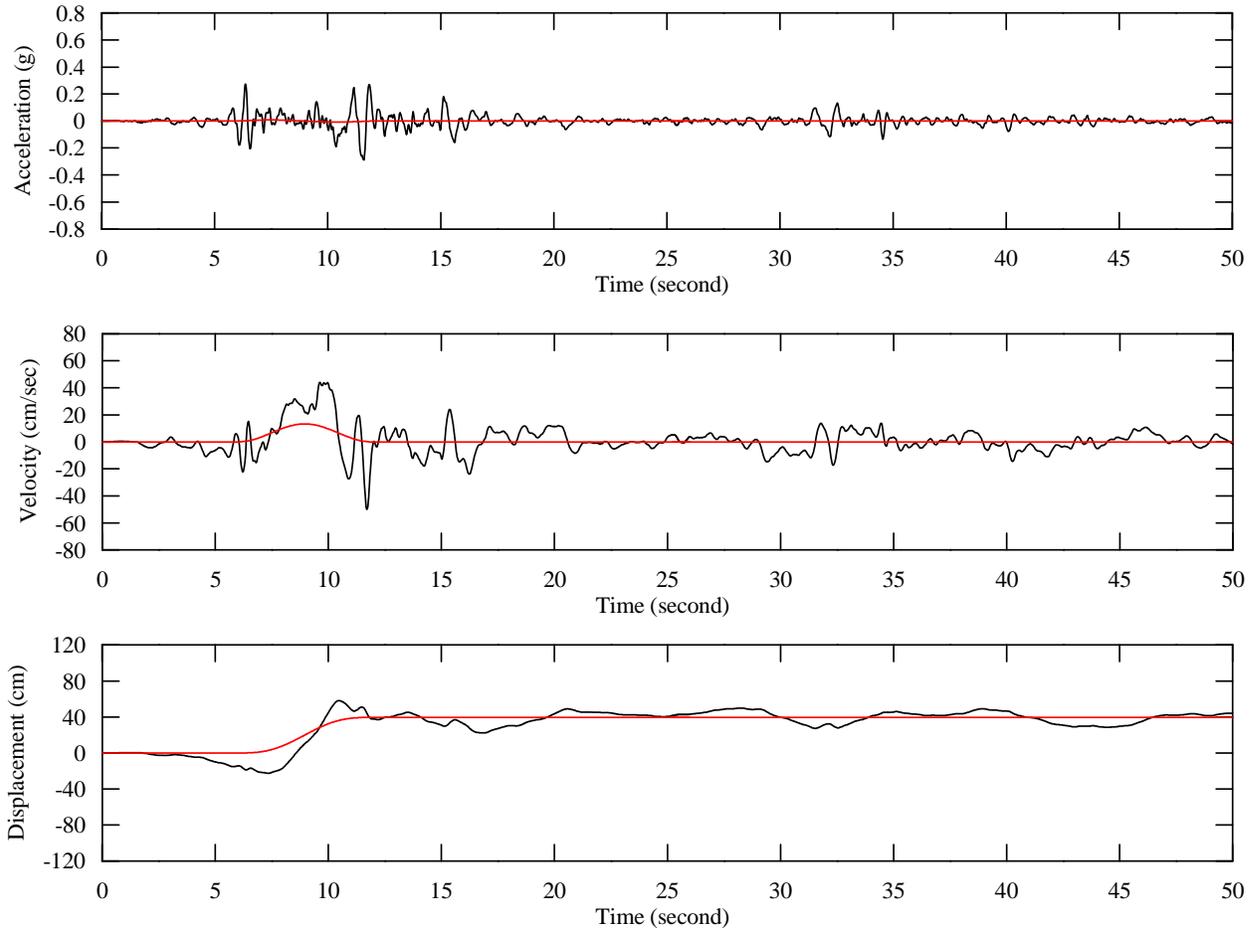


Figure 155: Fault parallel time histories including fling at top of side wall, 1990 Manjil Earthquake

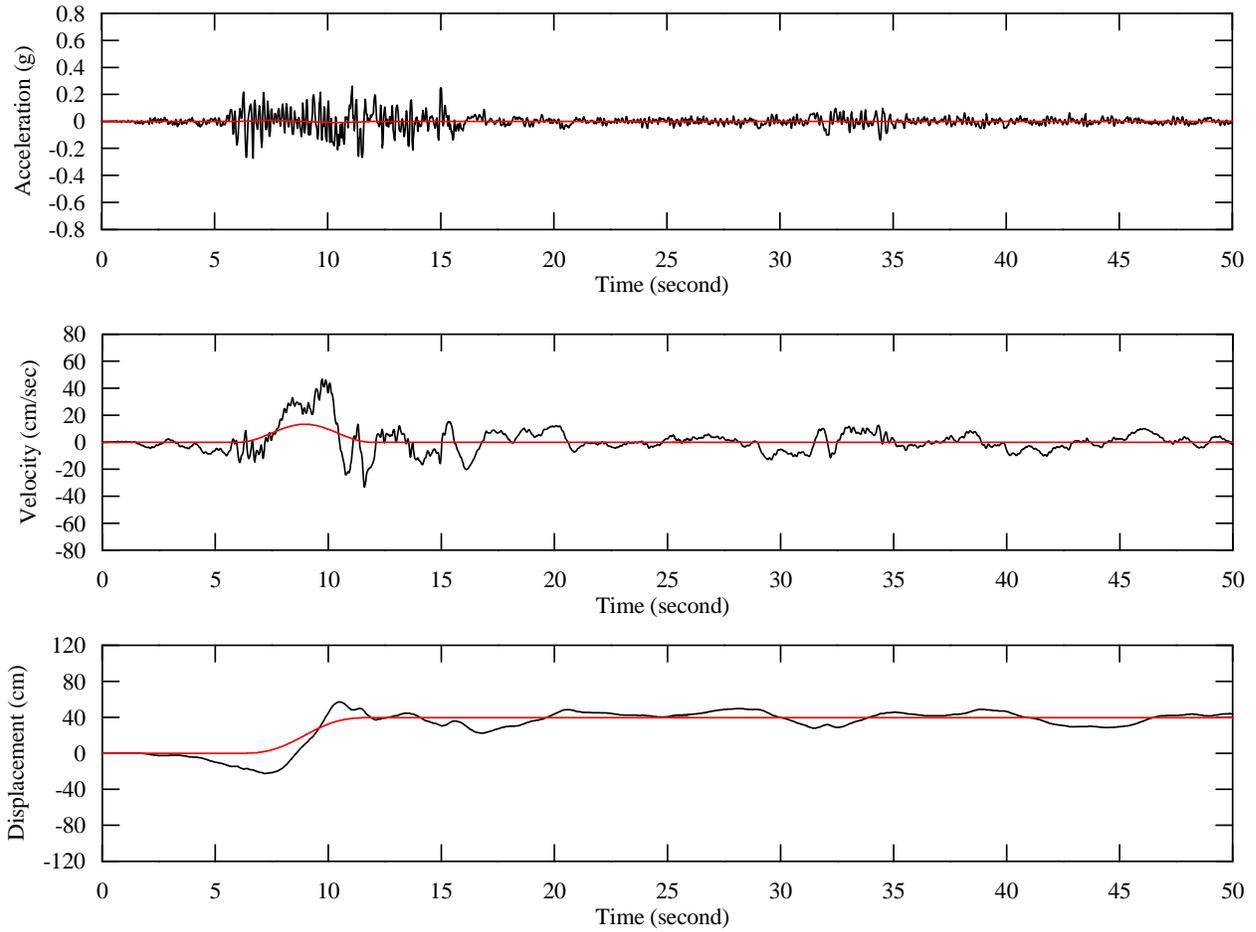


Figure 156: Fault parallel time histories including fling at invert of the tunnel, 1990 Manjil Earthquake

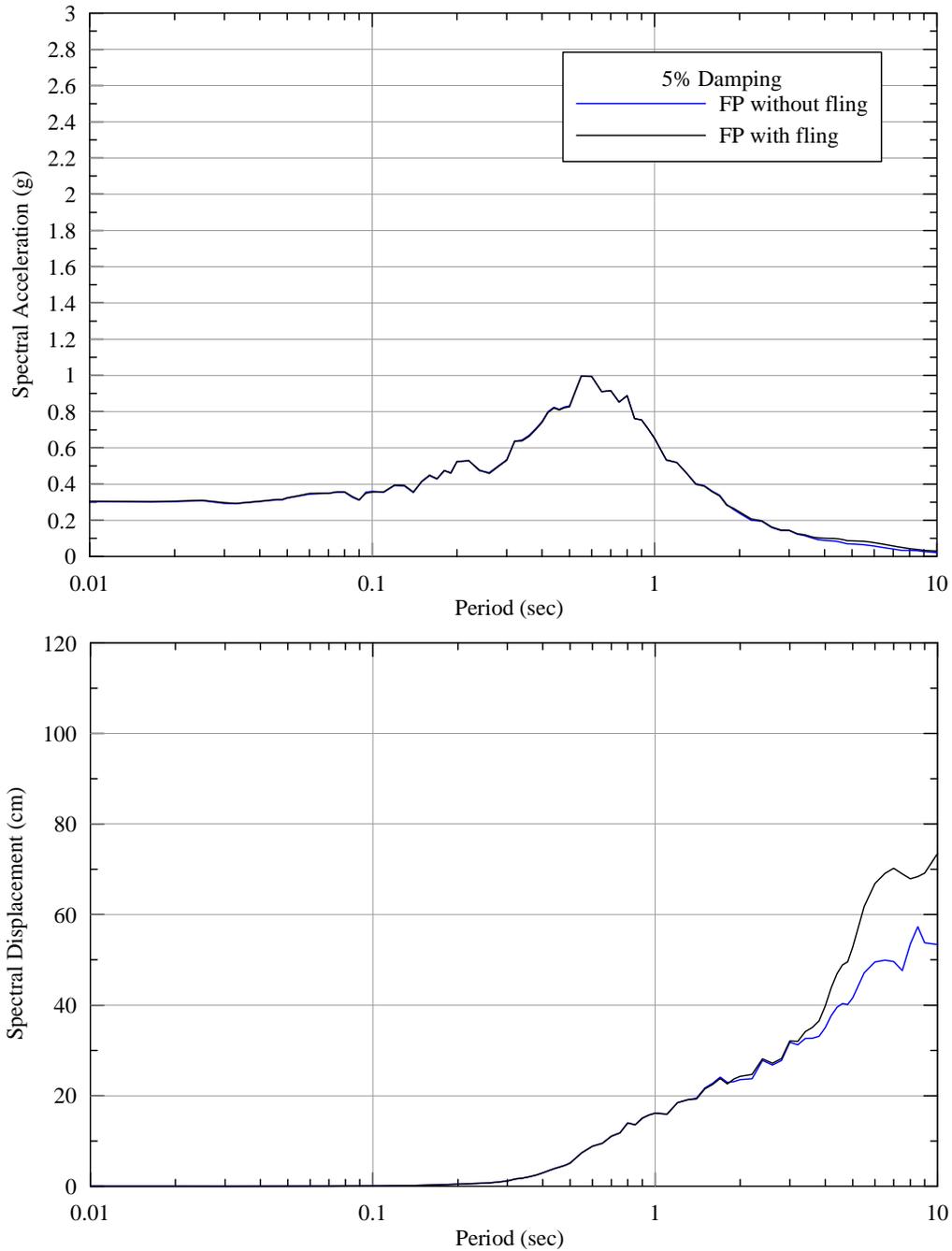


Figure 157: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1990 Manjil Earthquake

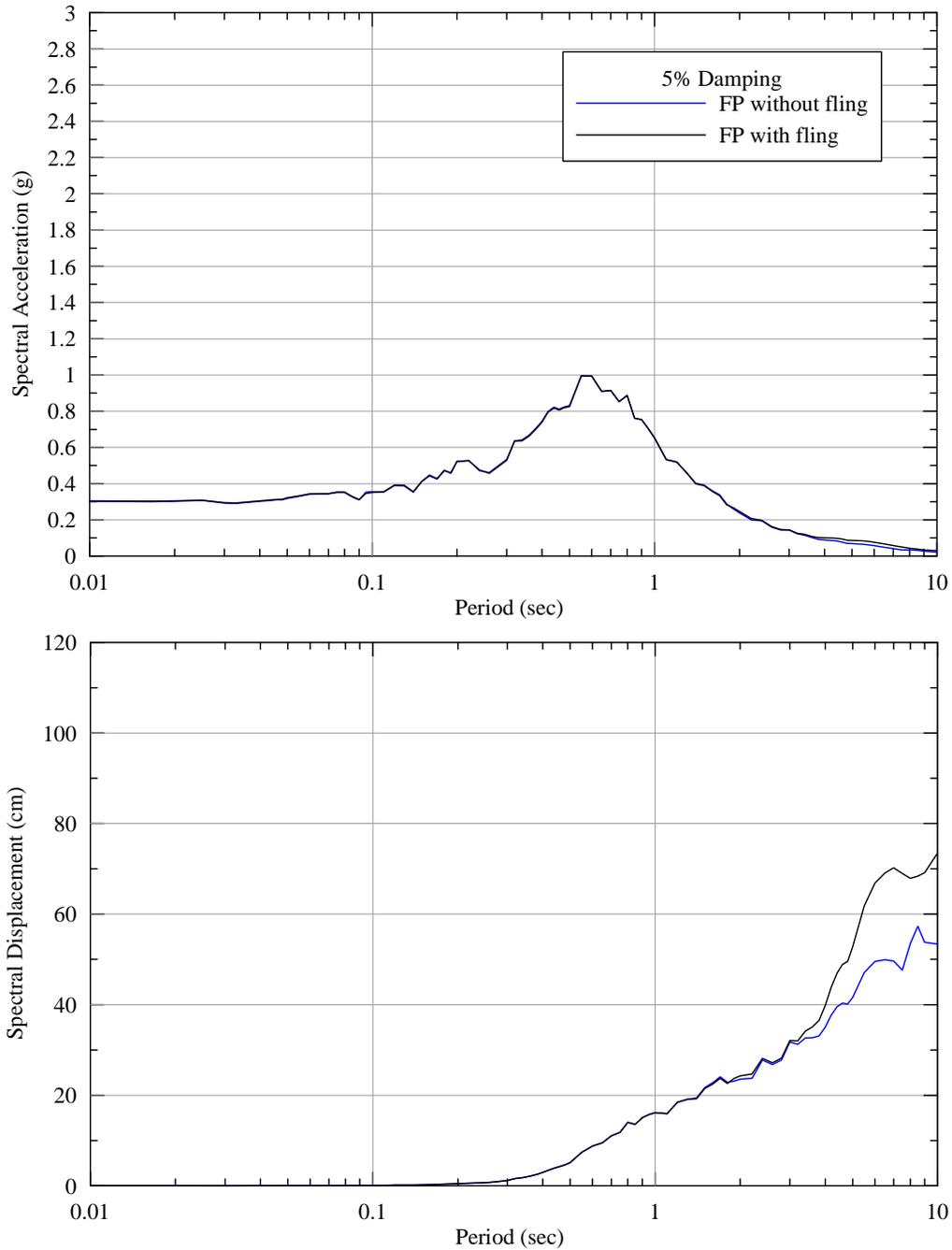


Figure 158: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1990 Manjil Earthquake

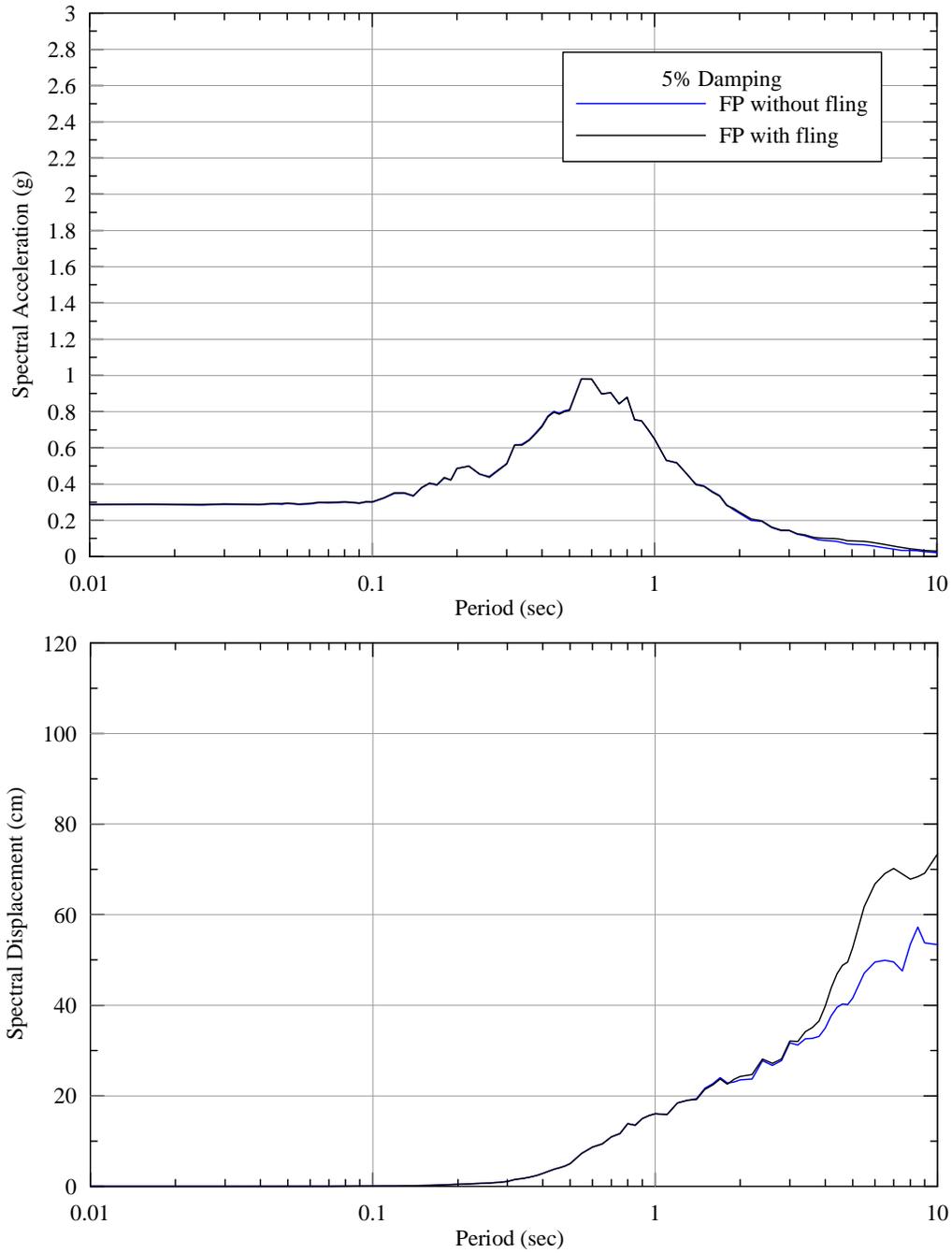


Figure 159: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1990 Manjil Earthquake

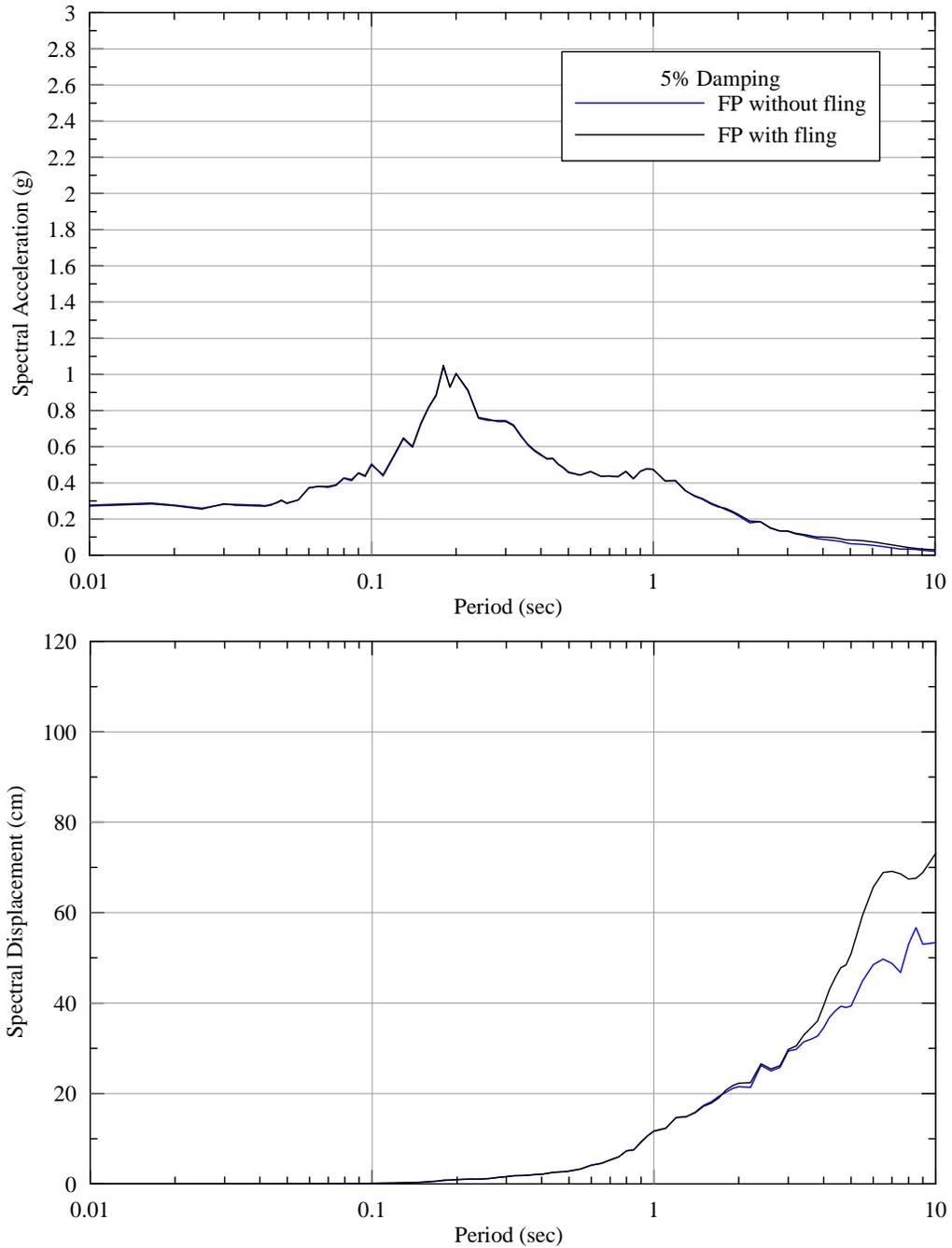


Figure 160: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1990 Manjil Earthquake

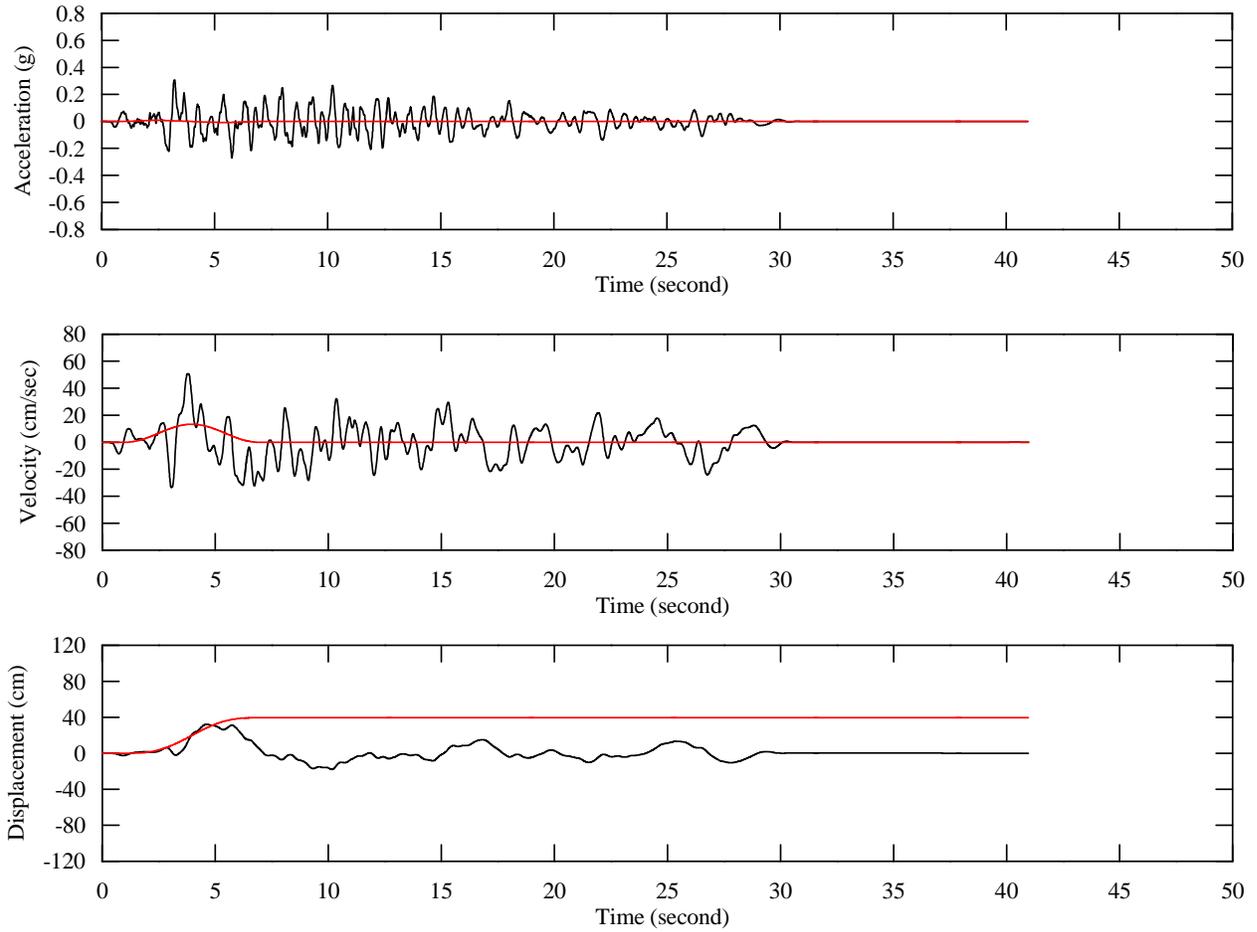


Figure 161: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1999 Kocaeli Earthquake

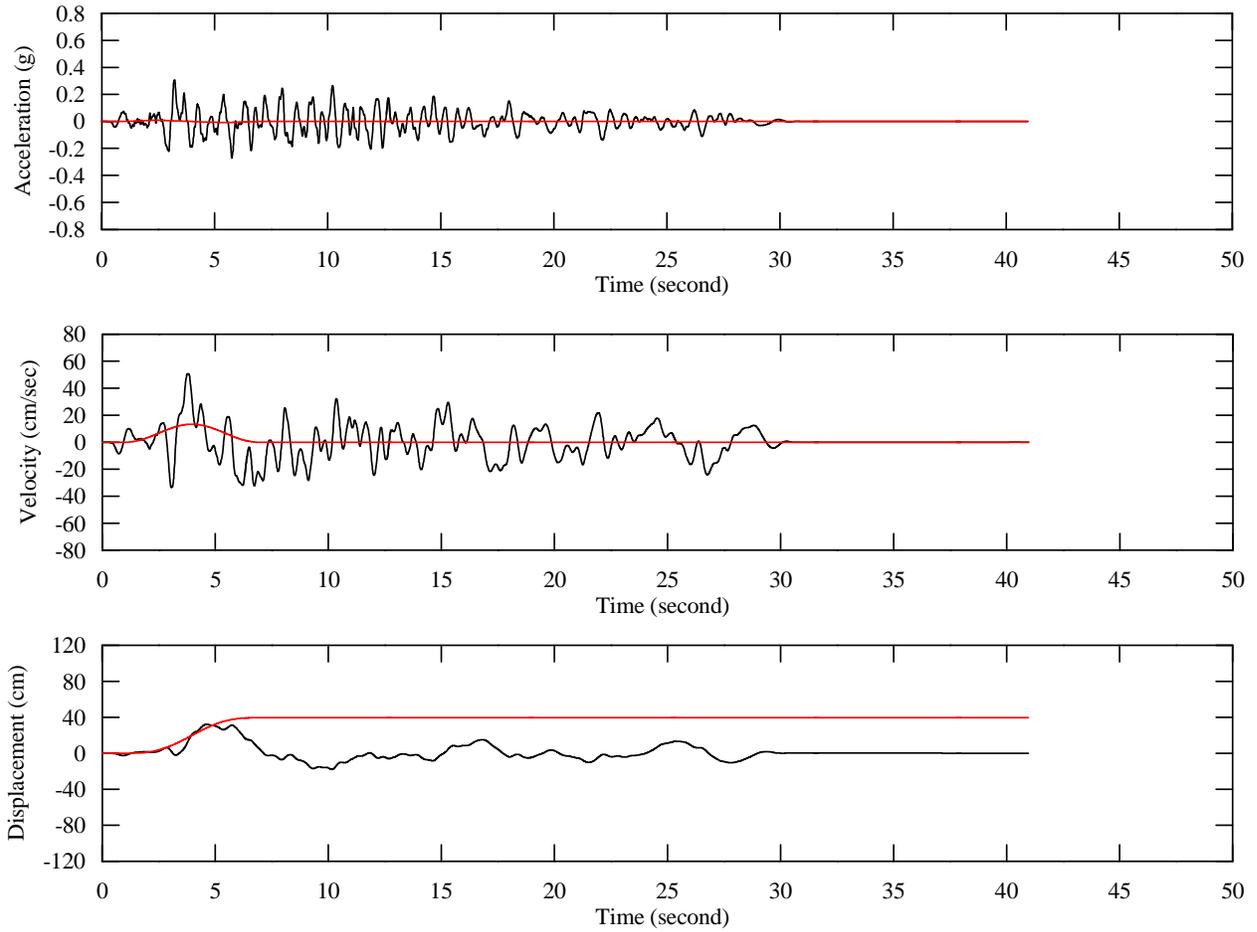


Figure 162: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1999 Kocaeli Earthquake

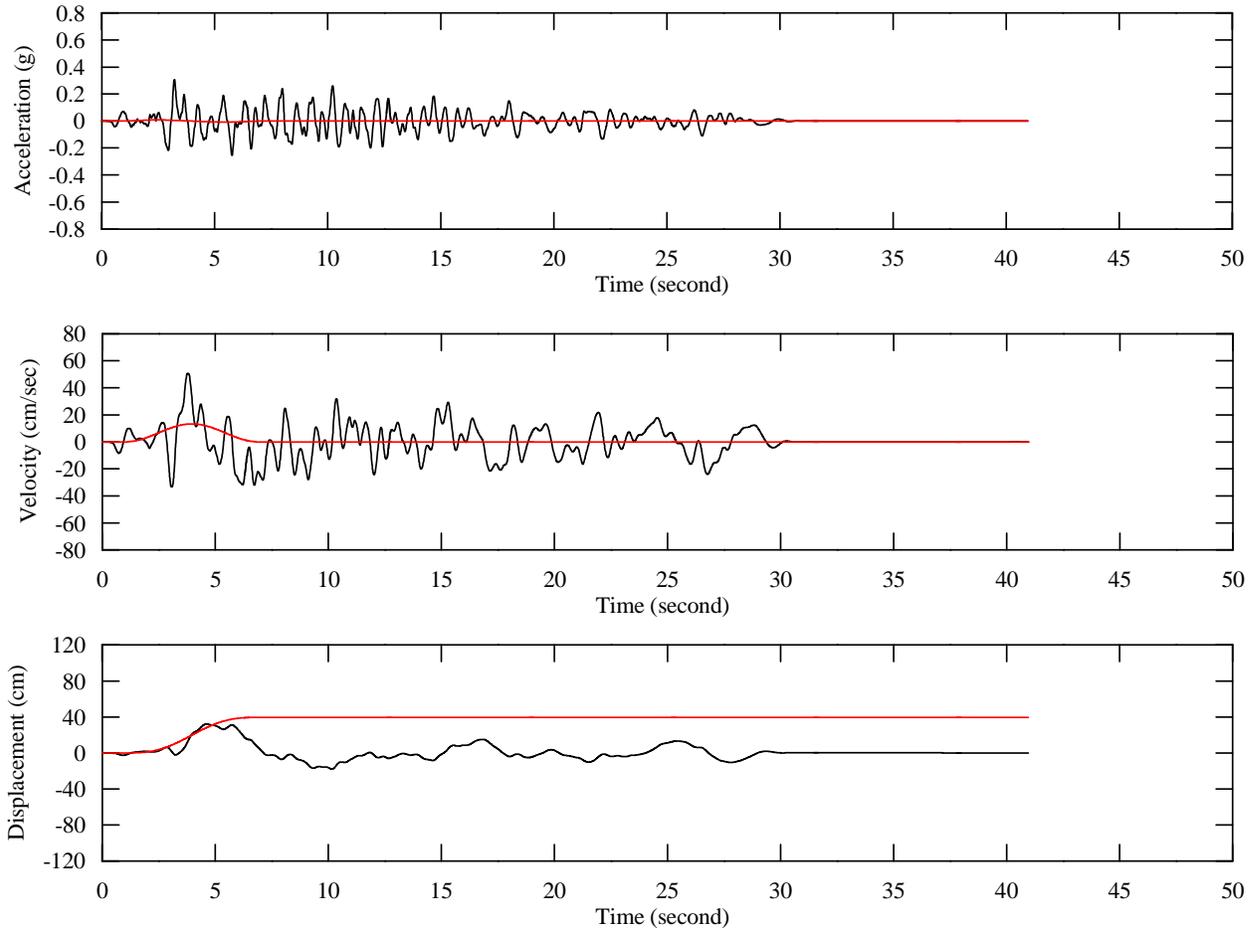


Figure 163: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1999 Kocaeli Earthquake

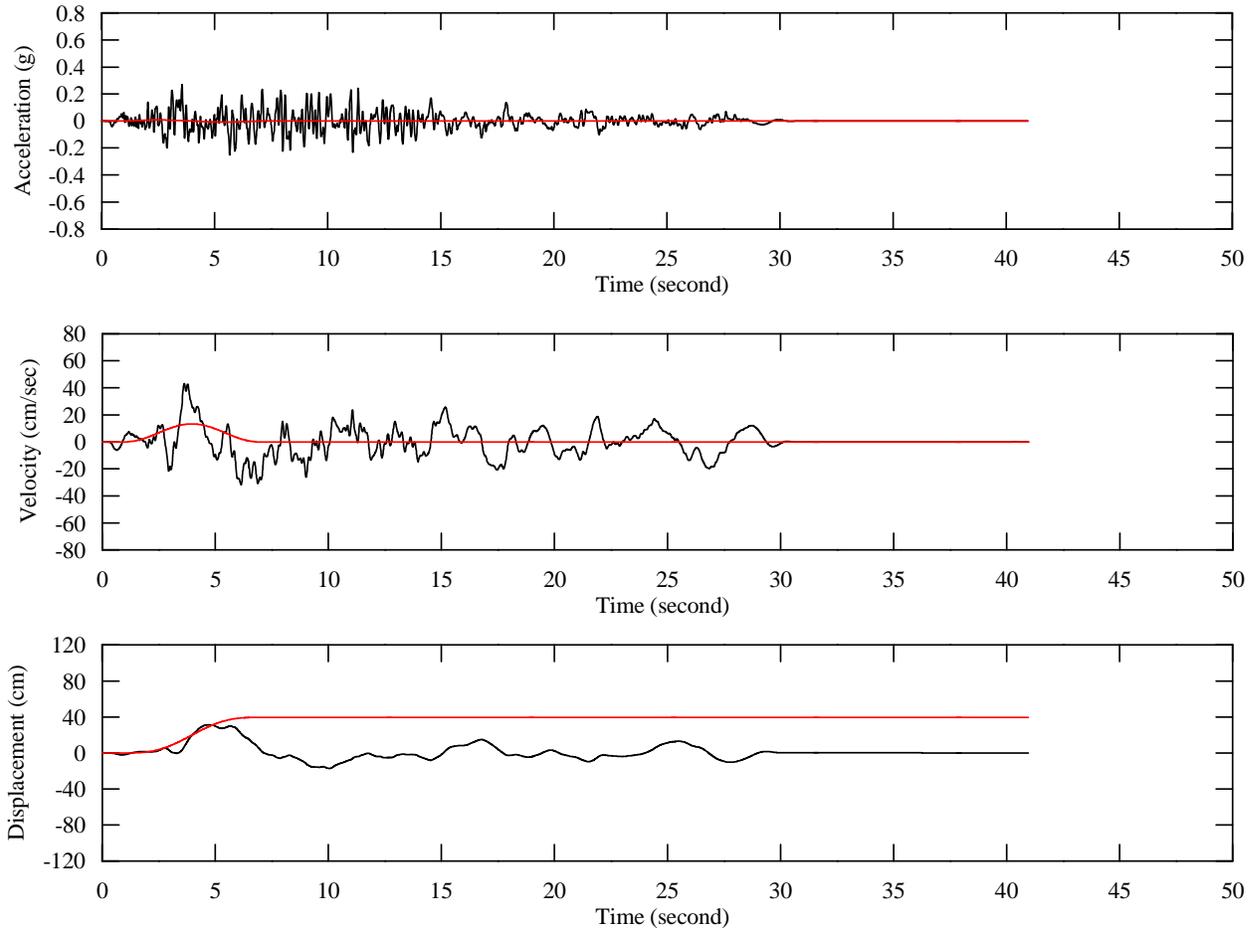


Figure 164: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1999 Kocaeli Earthquake

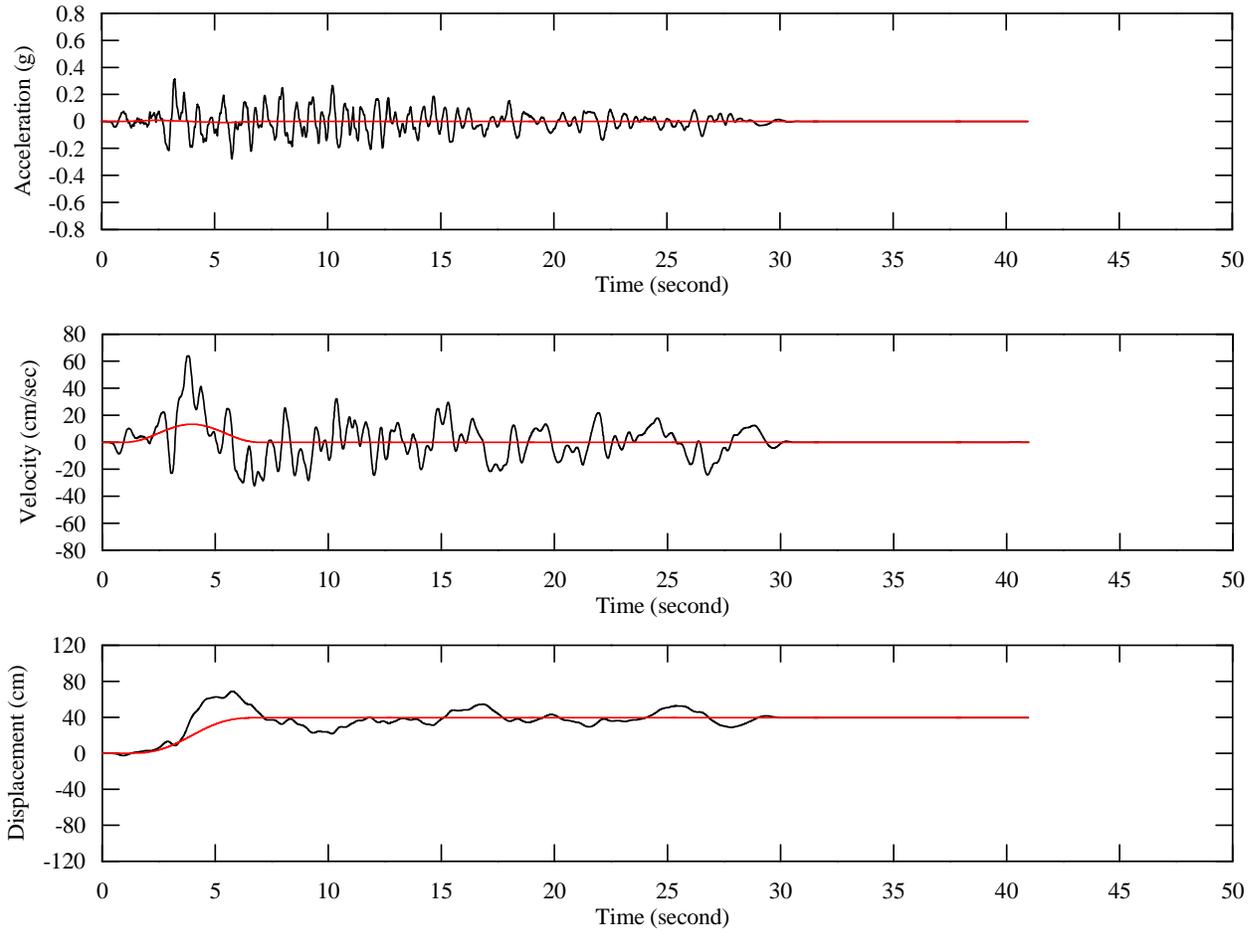


Figure 165: Fault parallel time histories including fling at ground surface, 1999 Kocaeli Earthquake

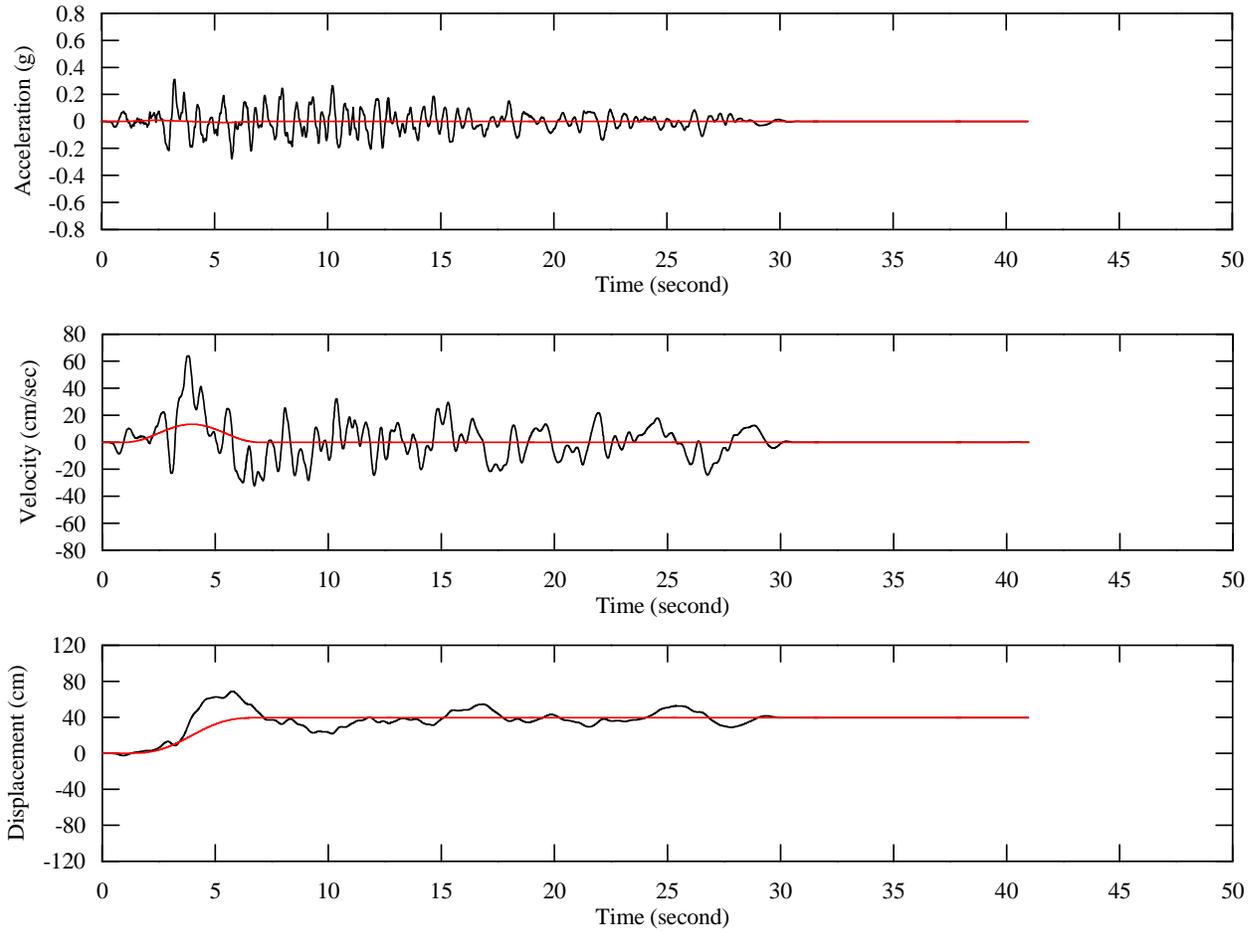


Figure 166: Fault parallel time histories including fling at crown of the tunnel, 1999 Kocaeli Earthquake

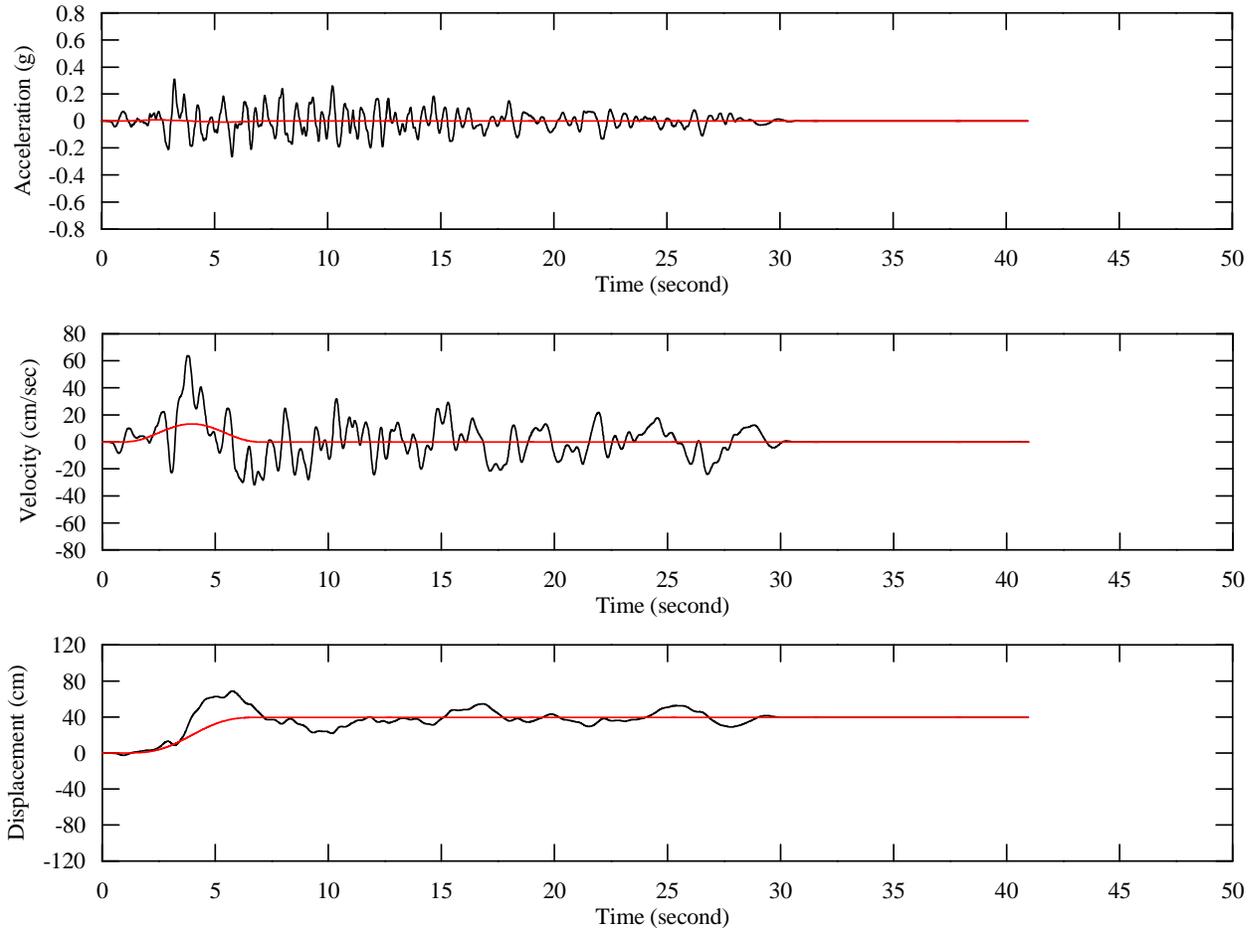


Figure 167: Fault parallel time histories including fling at top of side wall, 1999 Kocaeli Earthquake

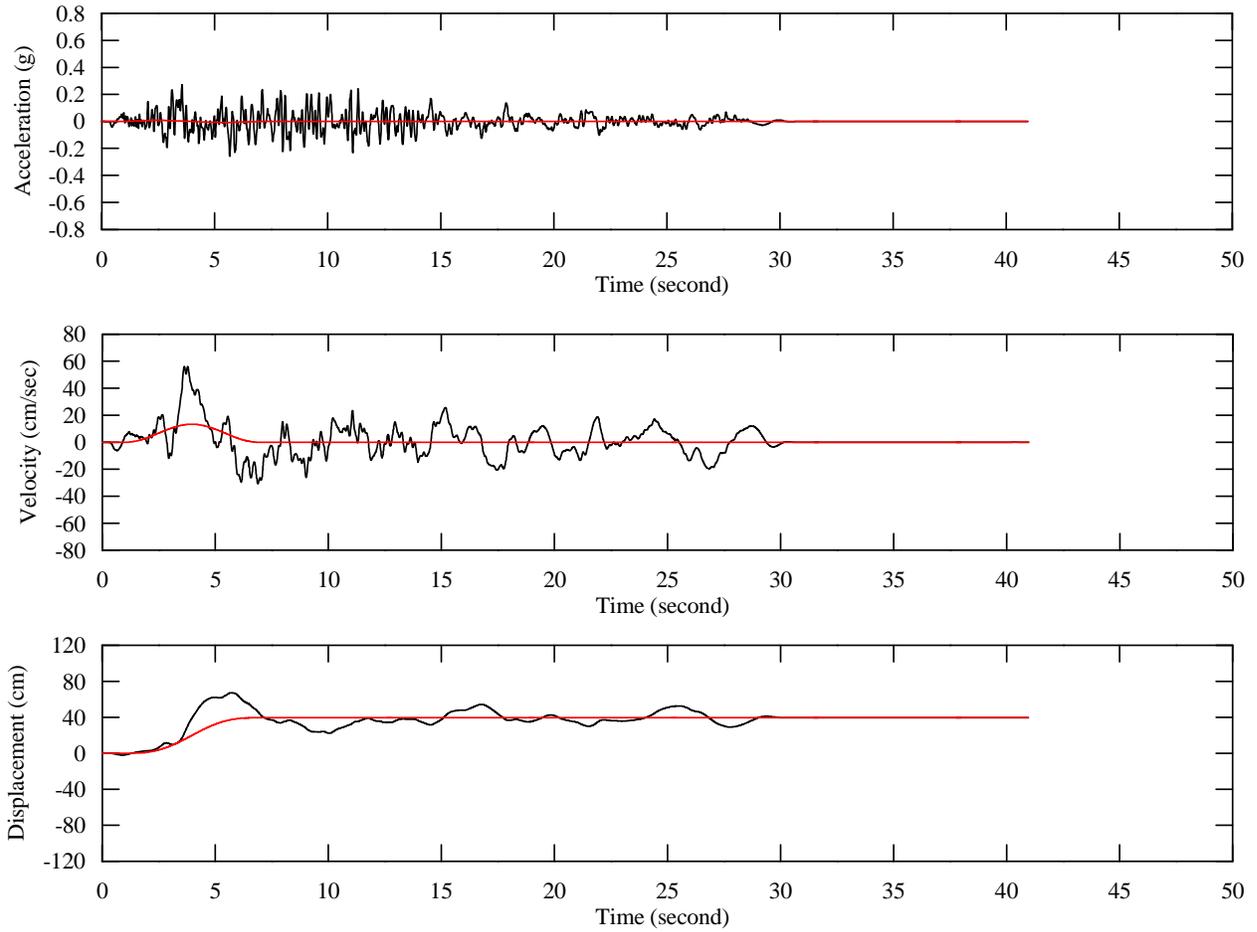


Figure 168: Fault parallel time histories including fling at invert of the tunnel, 1999 Kocaeli Earthquake

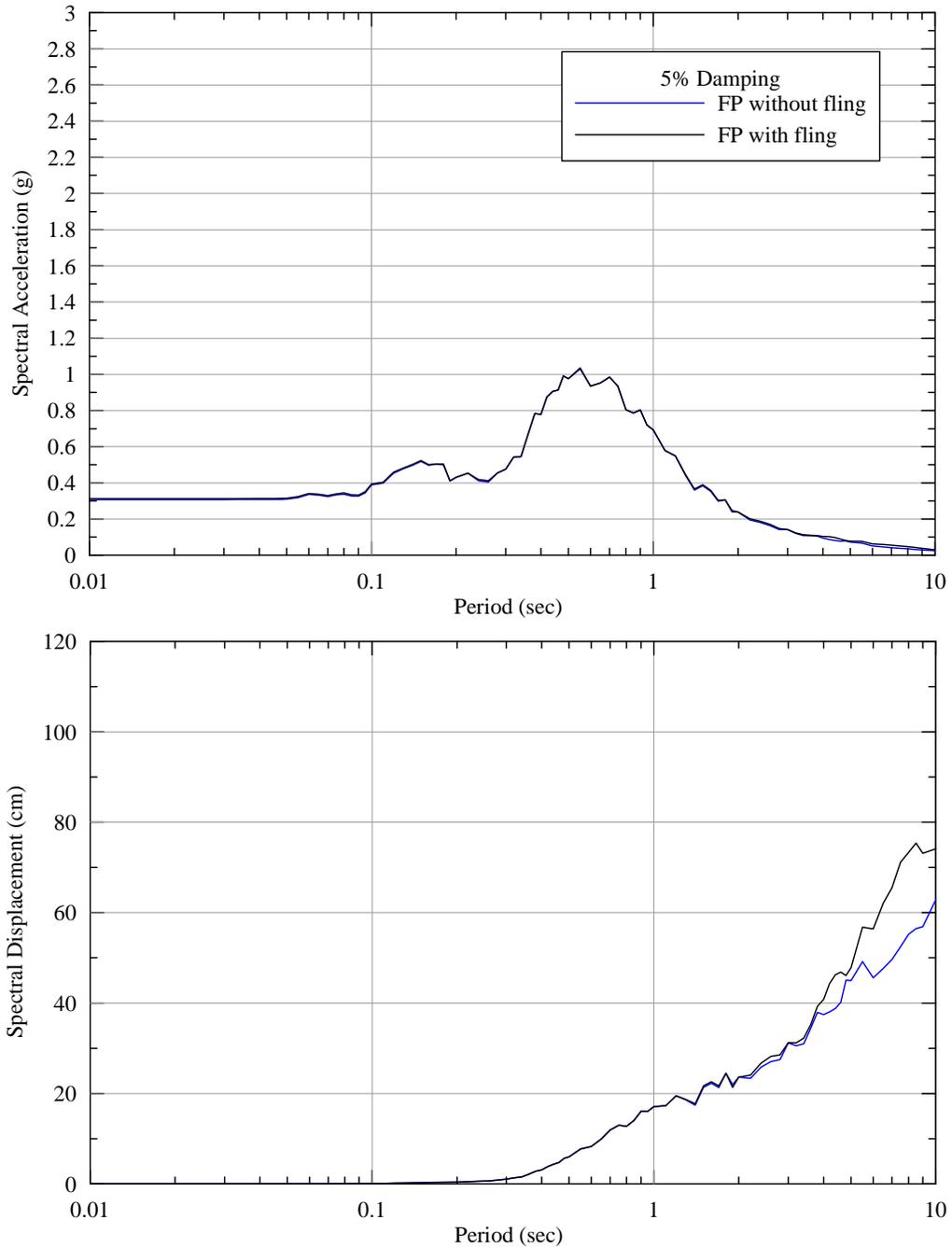


Figure 169: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1999 Kocaeli Earthquake

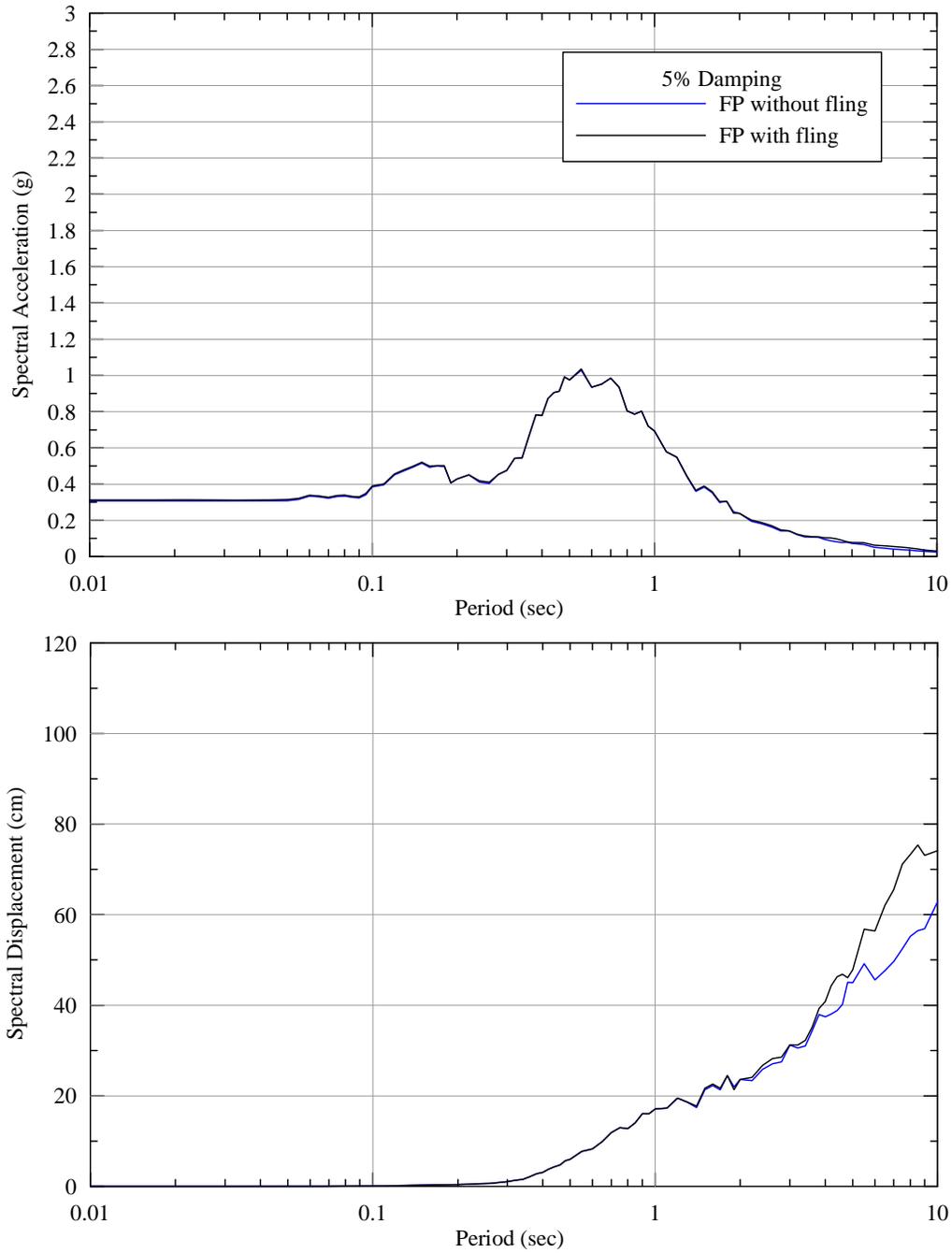


Figure 170: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1999 Kocaeli Earthquake

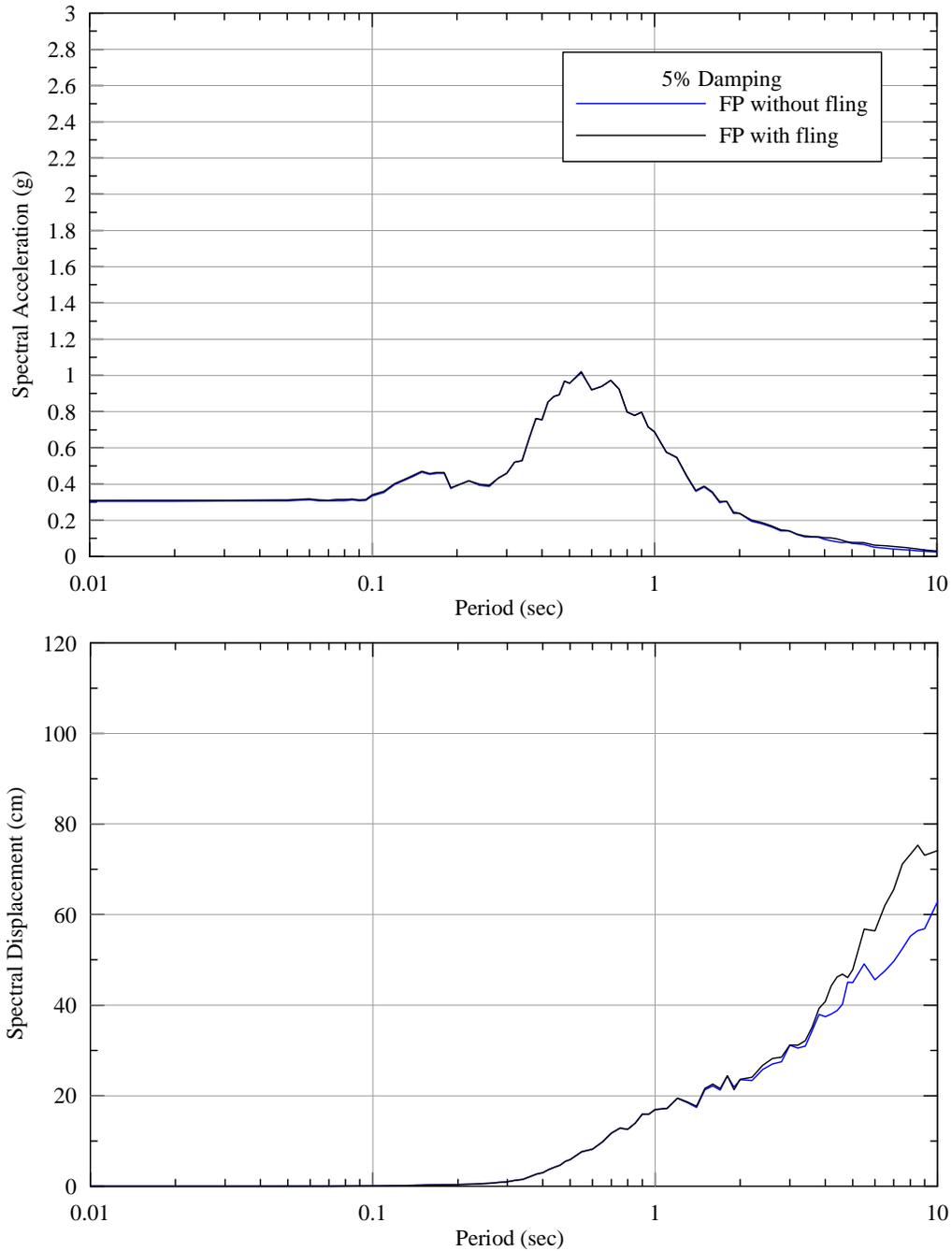


Figure 171: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1999 Kocaeli Earthquake

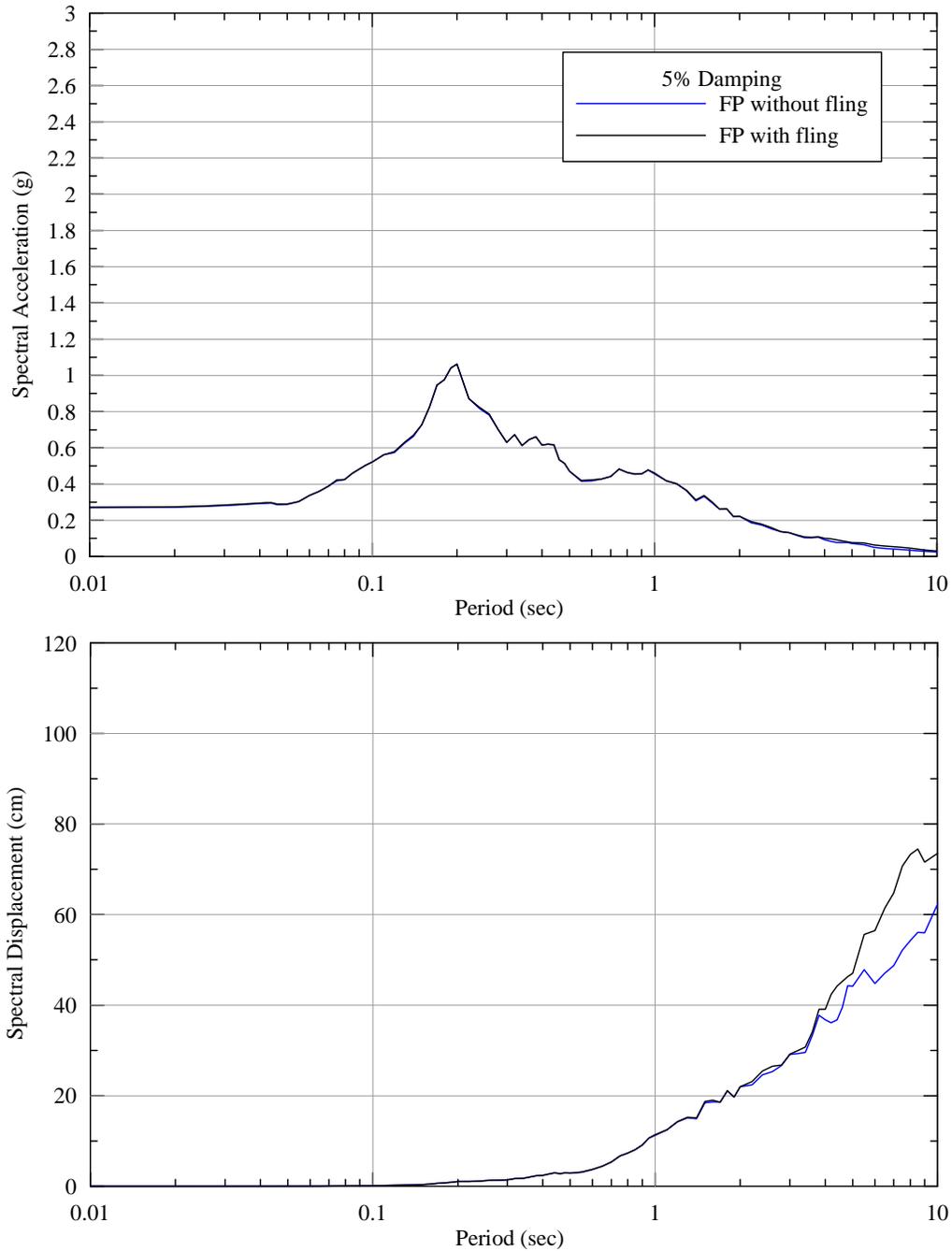


Figure 172: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1999 Kocaeli Earthquake

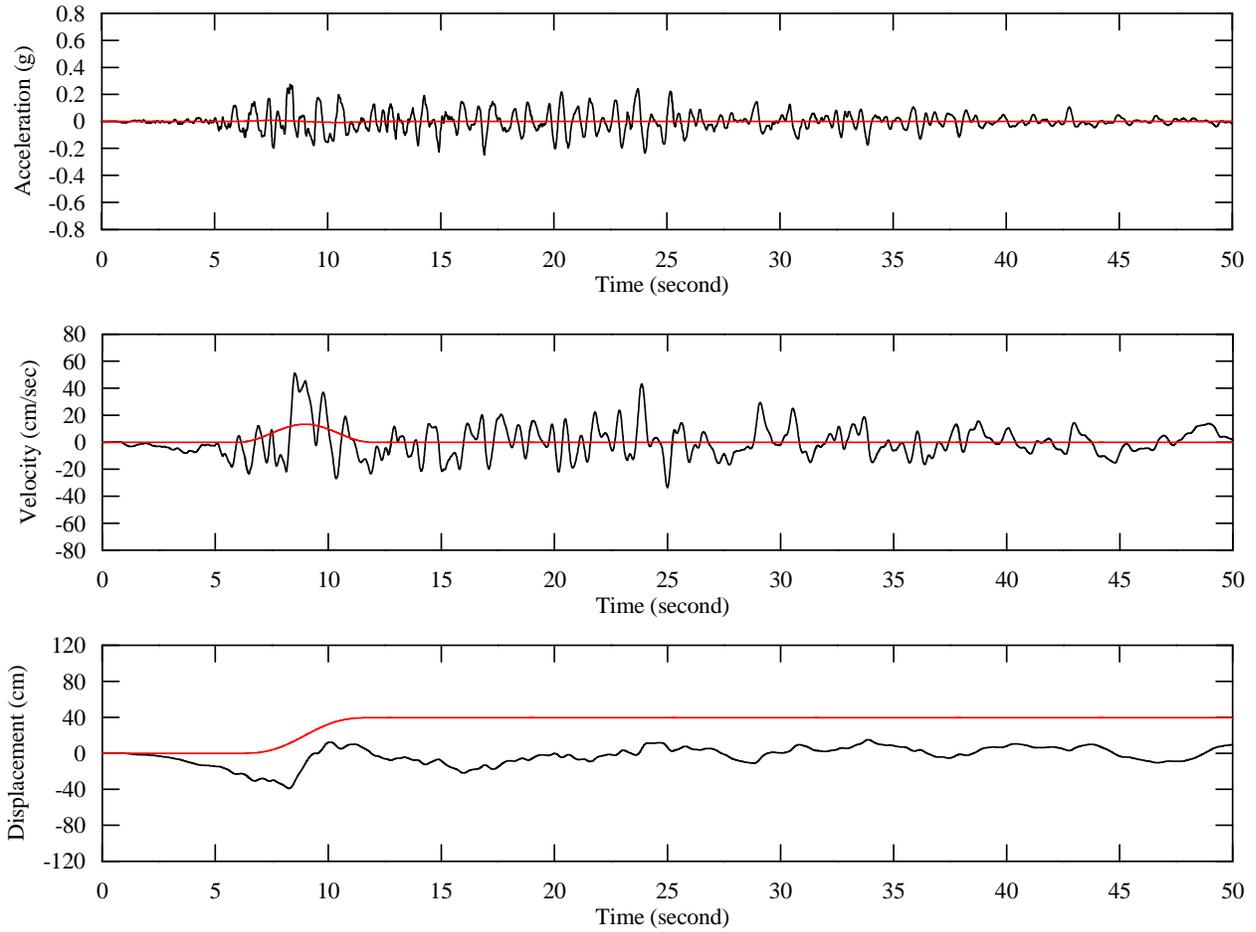


Figure 173: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

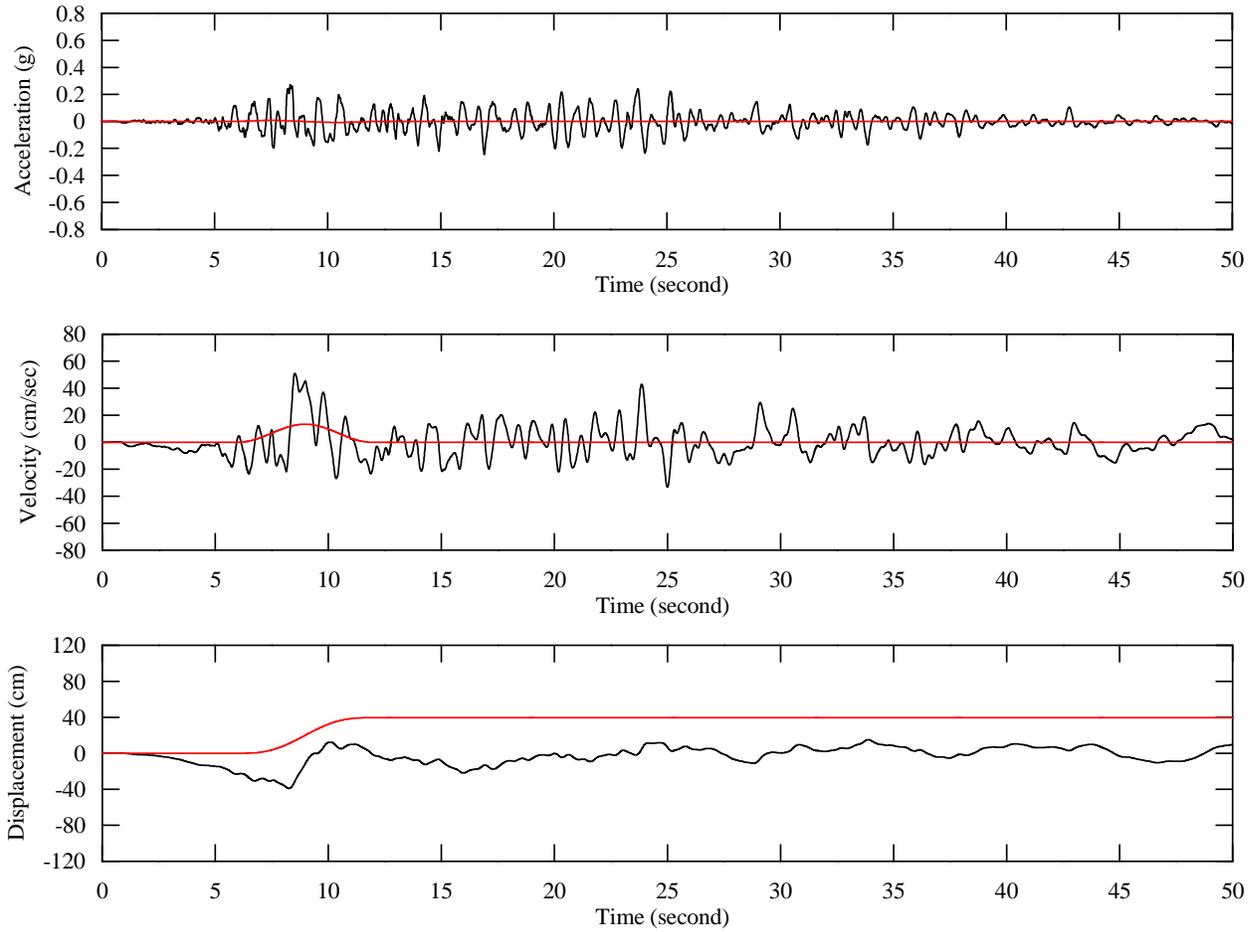


Figure 174: Fault parallel time histories at crown of the tunnel from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

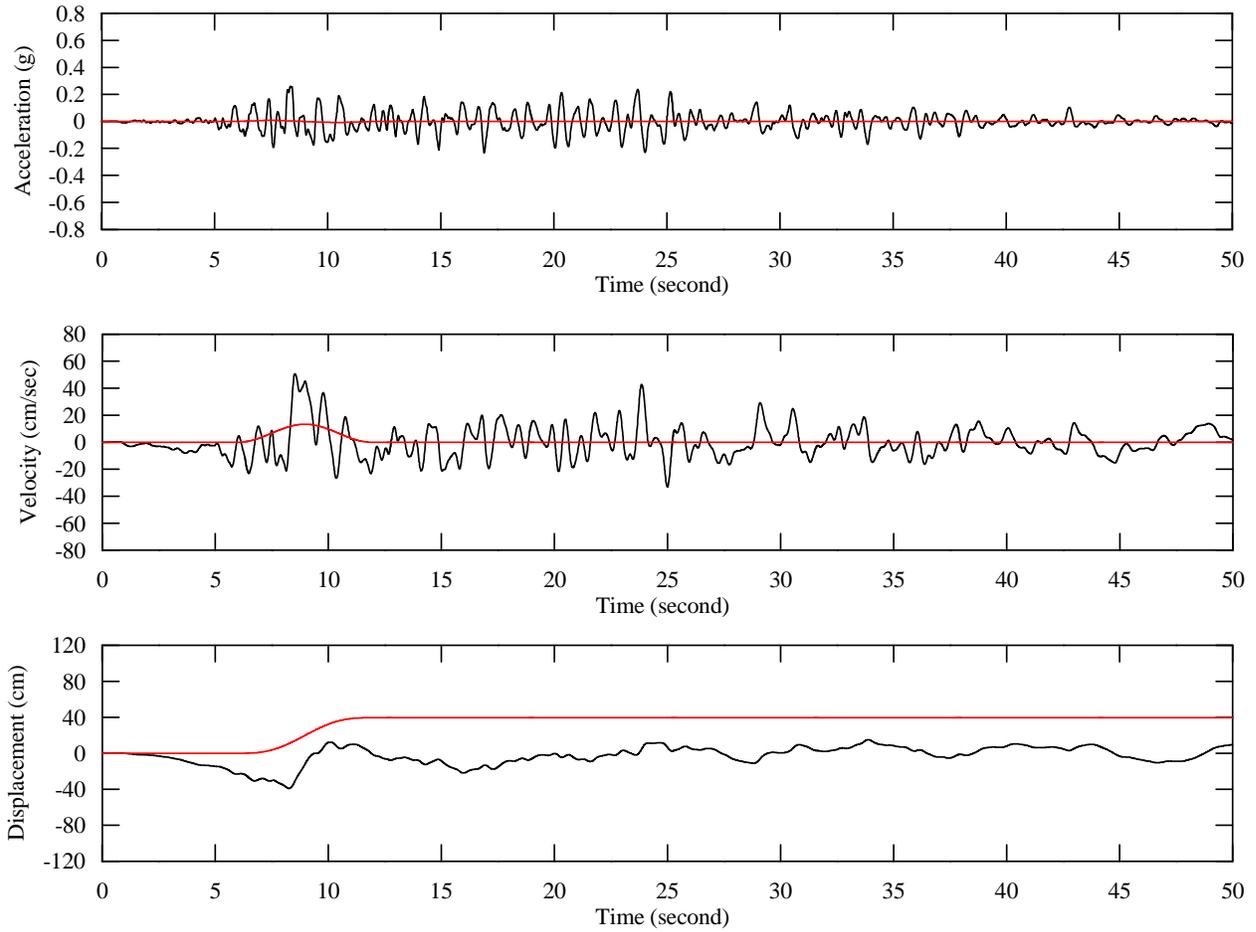


Figure 175: Fault parallel time histories at top of side wall from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

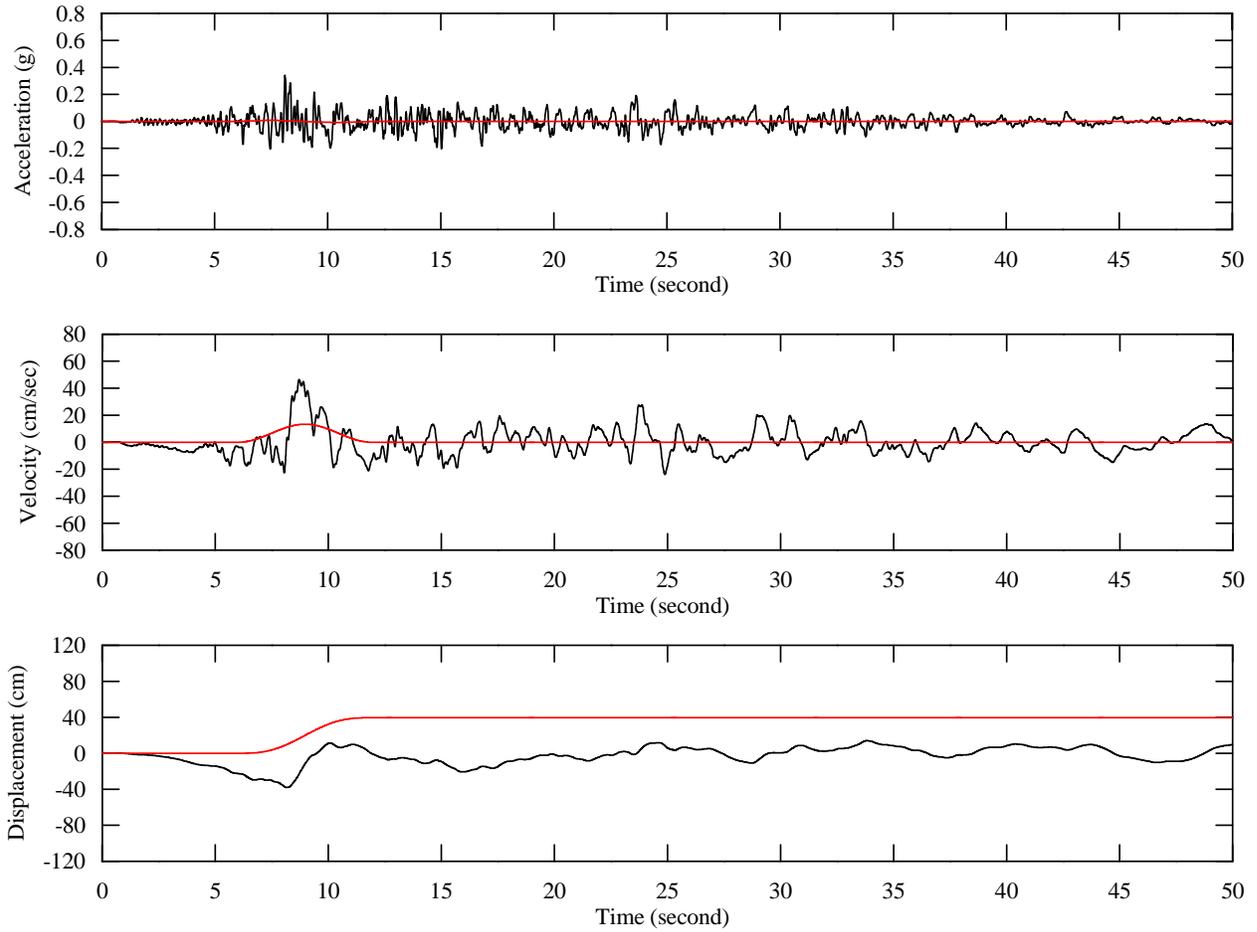


Figure 176: Fault parallel time histories at invert of the tunnel from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

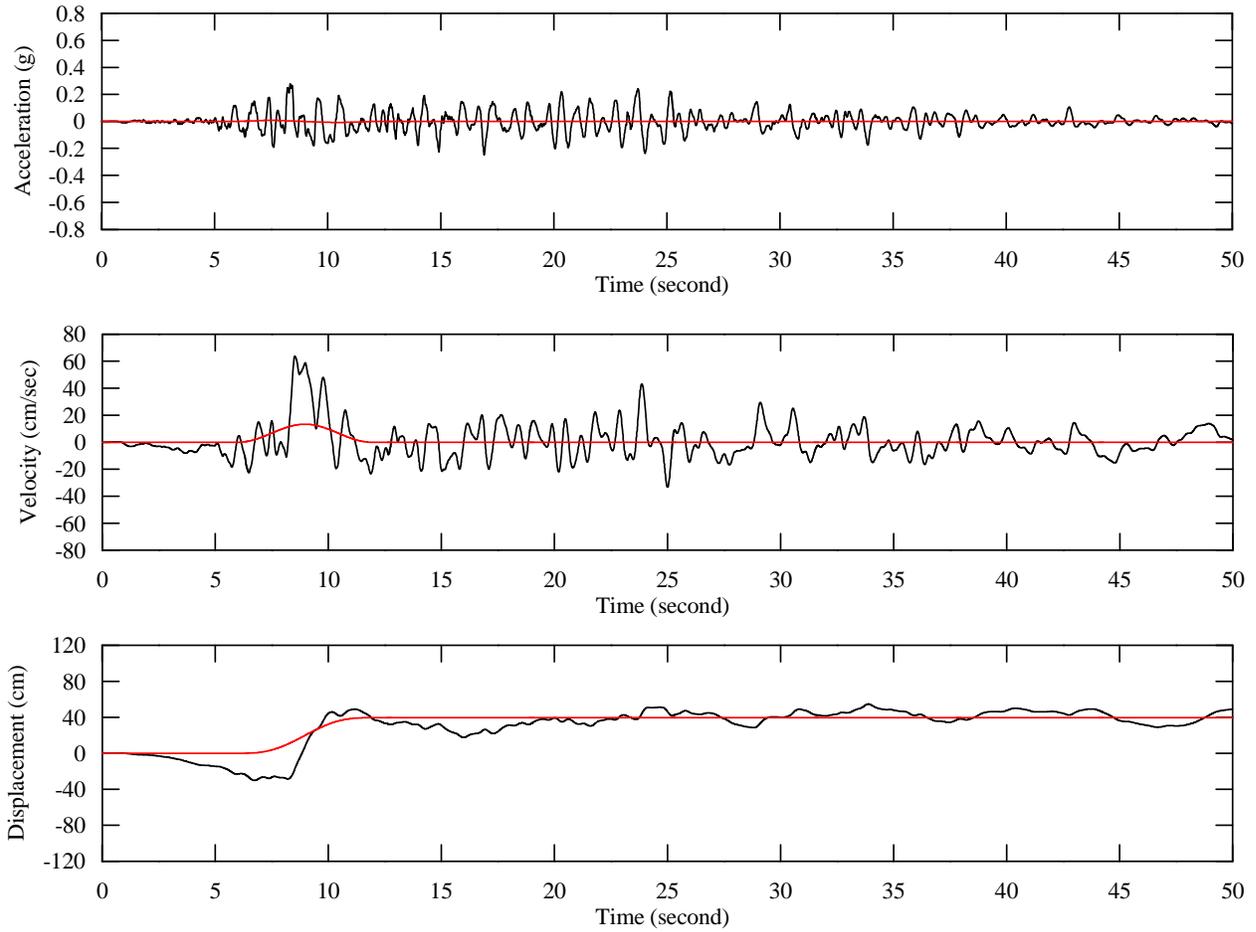


Figure 177: Fault parallel time histories including fling at ground surface, 1999 Chi-Chi Earthquake

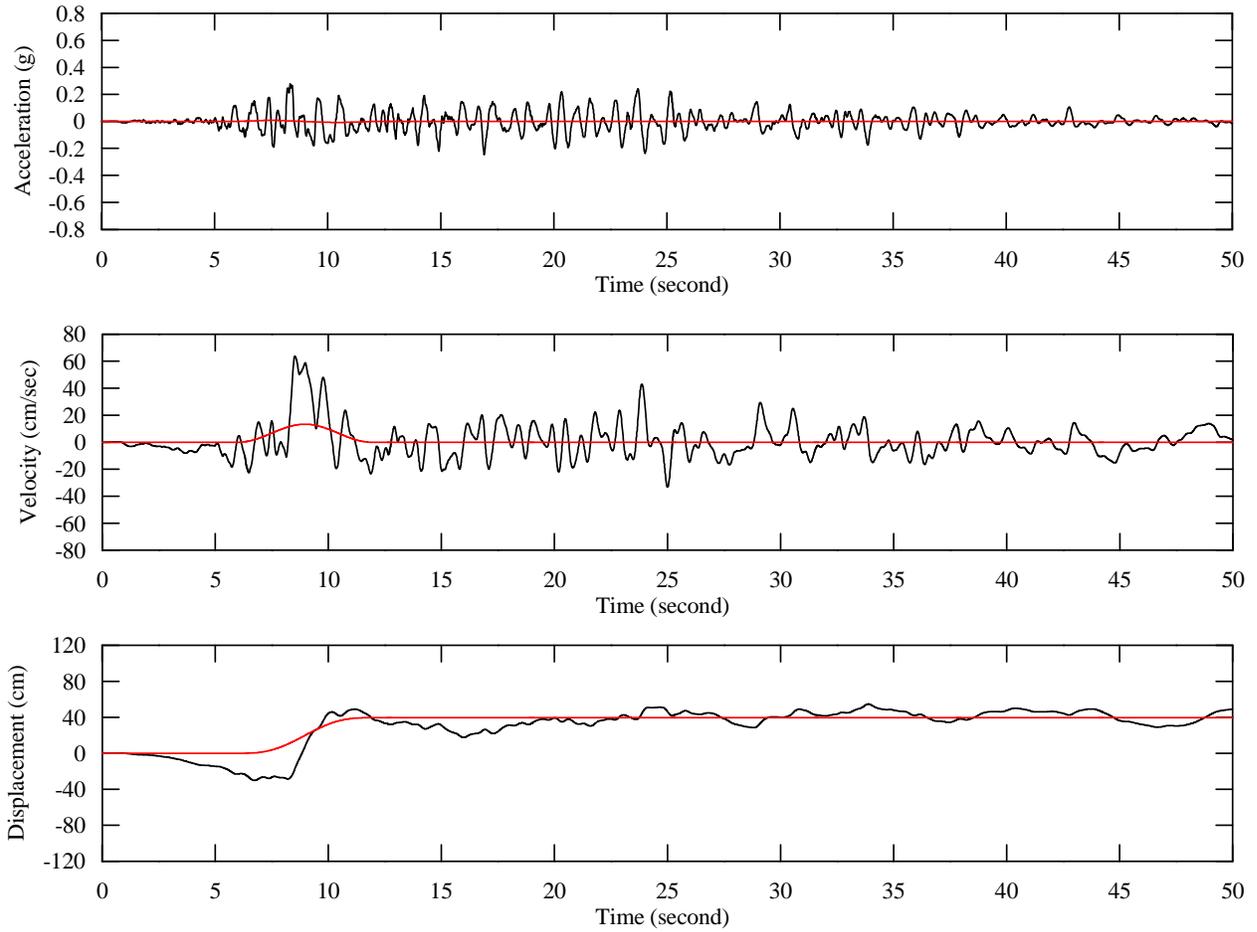


Figure 178: Fault parallel time histories including fling at crown of the tunnel, 1999 Chi-Chi Earthquake

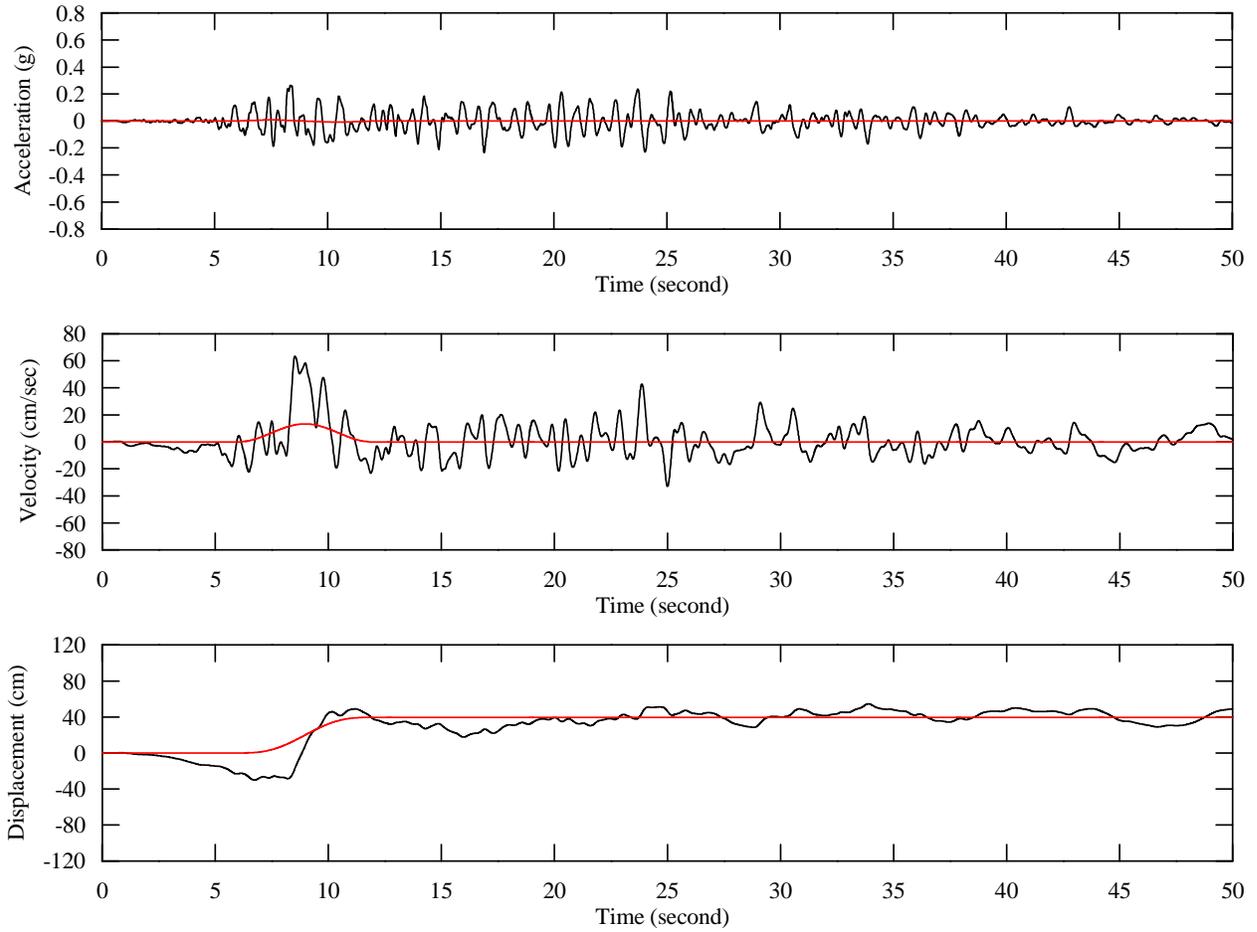


Figure 179: Fault parallel time histories including fling at top of side wall, 1999 Chi-Chi Earthquake

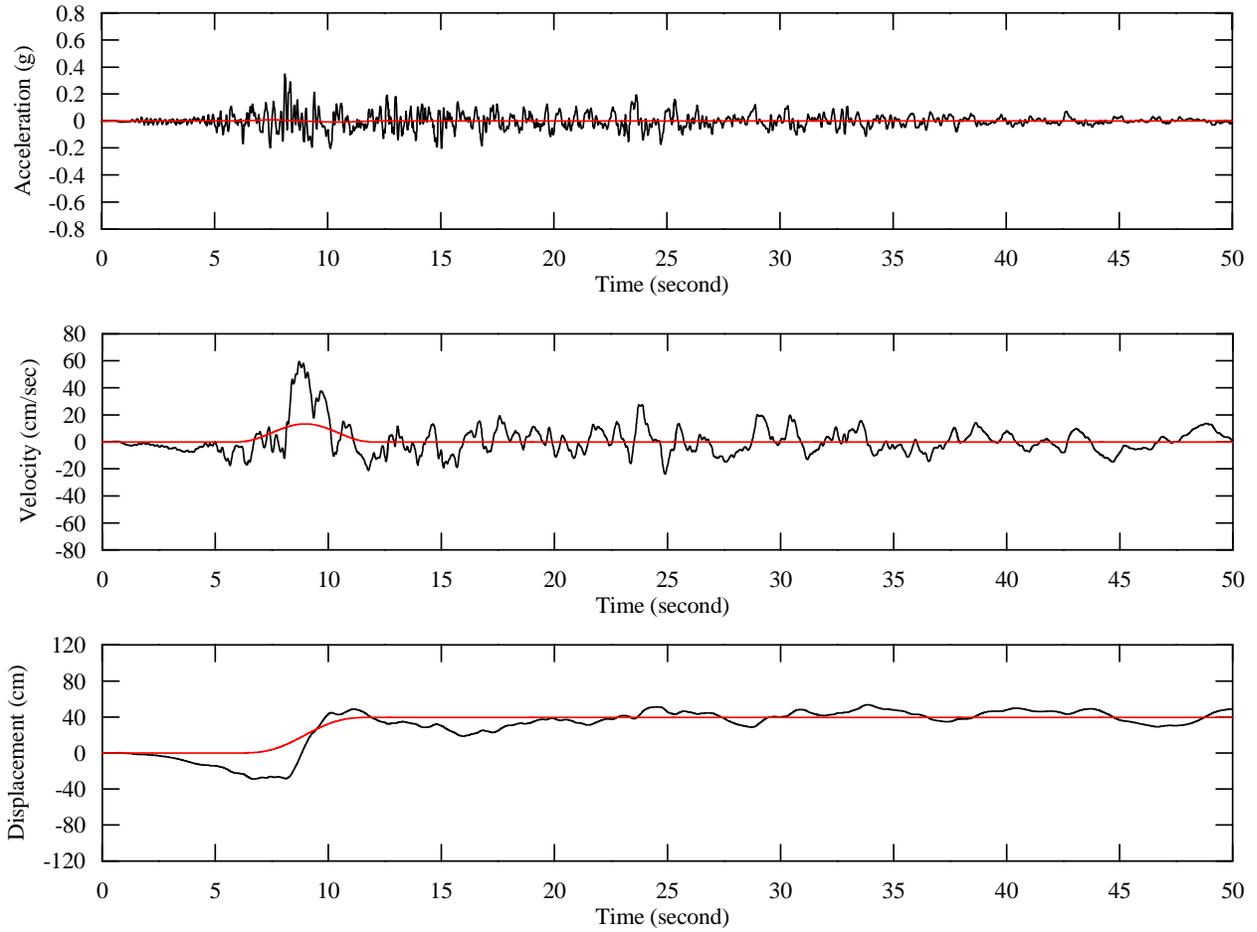


Figure 180: Fault parallel time histories including fling at invert of the tunnel, 1999 Chi-Chi Earthquake

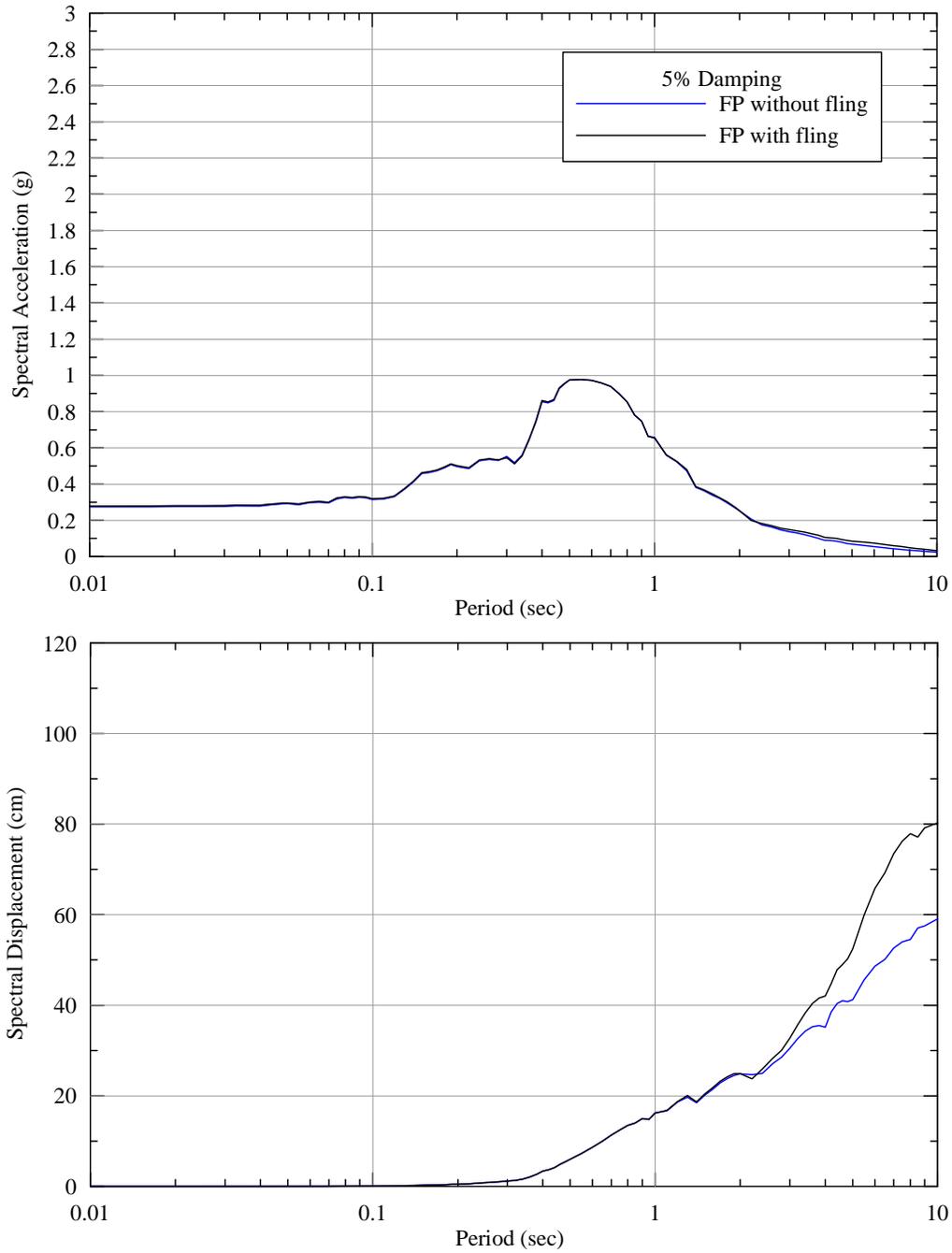


Figure 181: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1999 Chi-Chi Earthquake

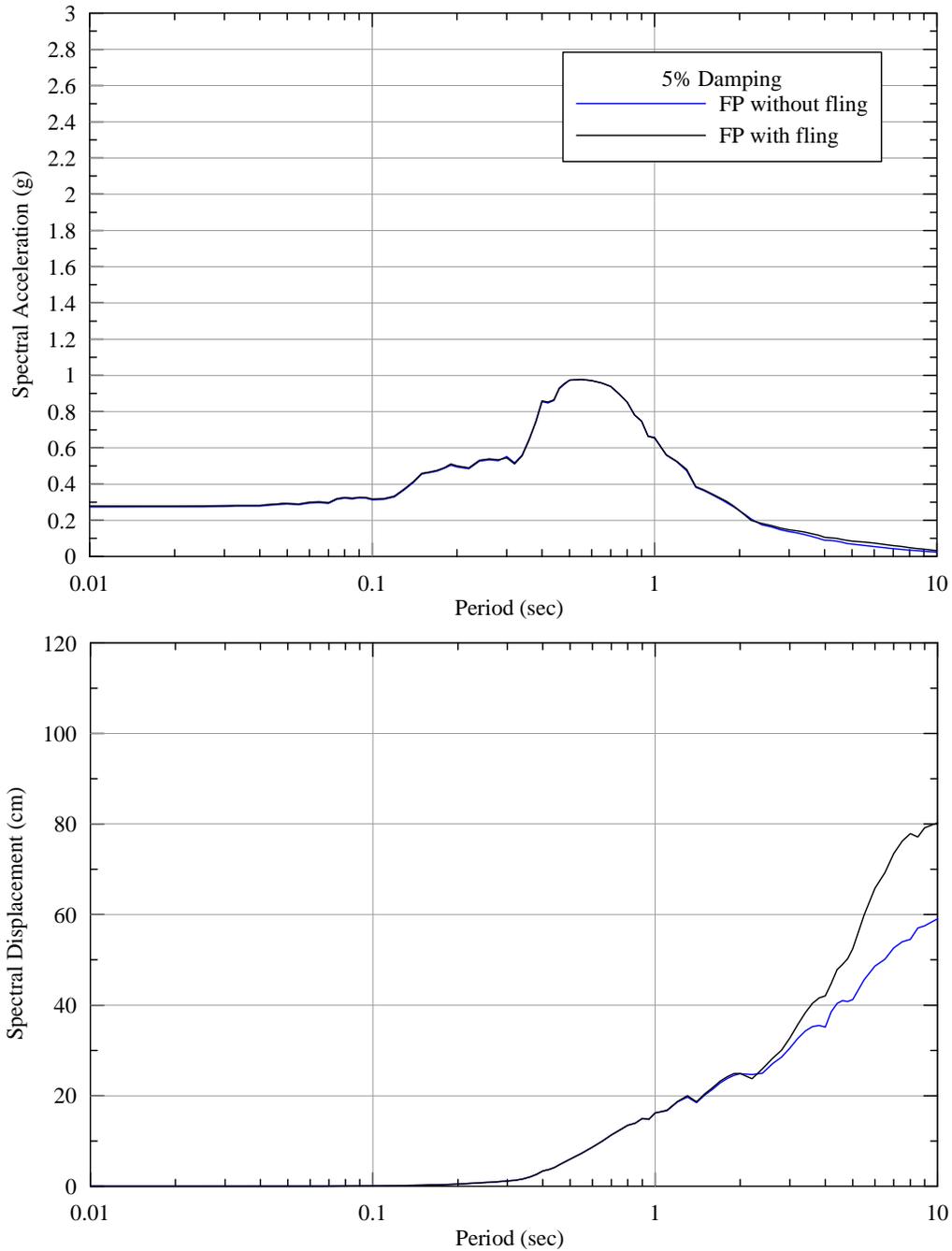


Figure 182: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at crown of the tunnel, 1999 Chi-Chi Earthquake

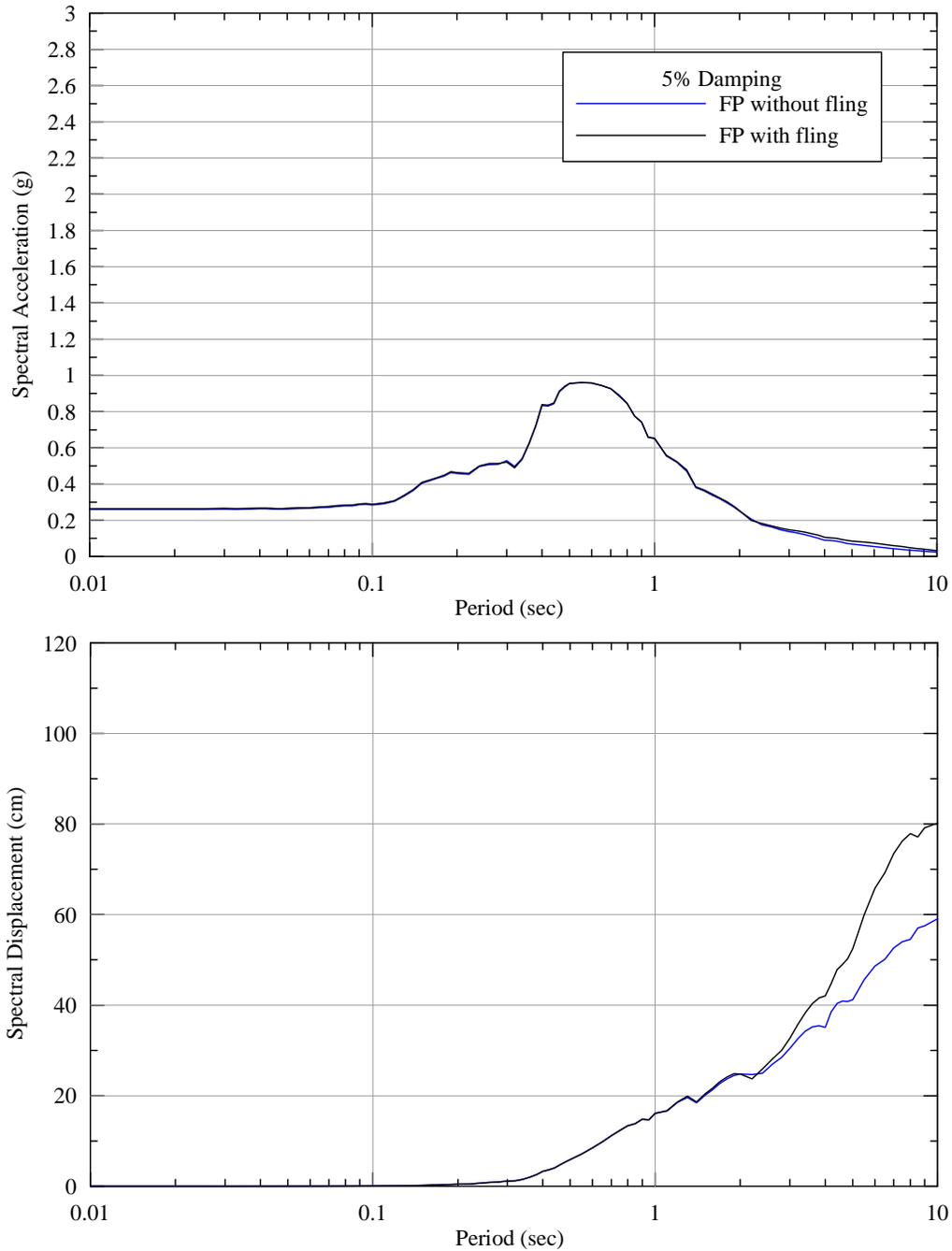


Figure 183: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at top of side wall, 1999 Chi-Chi Earthquake

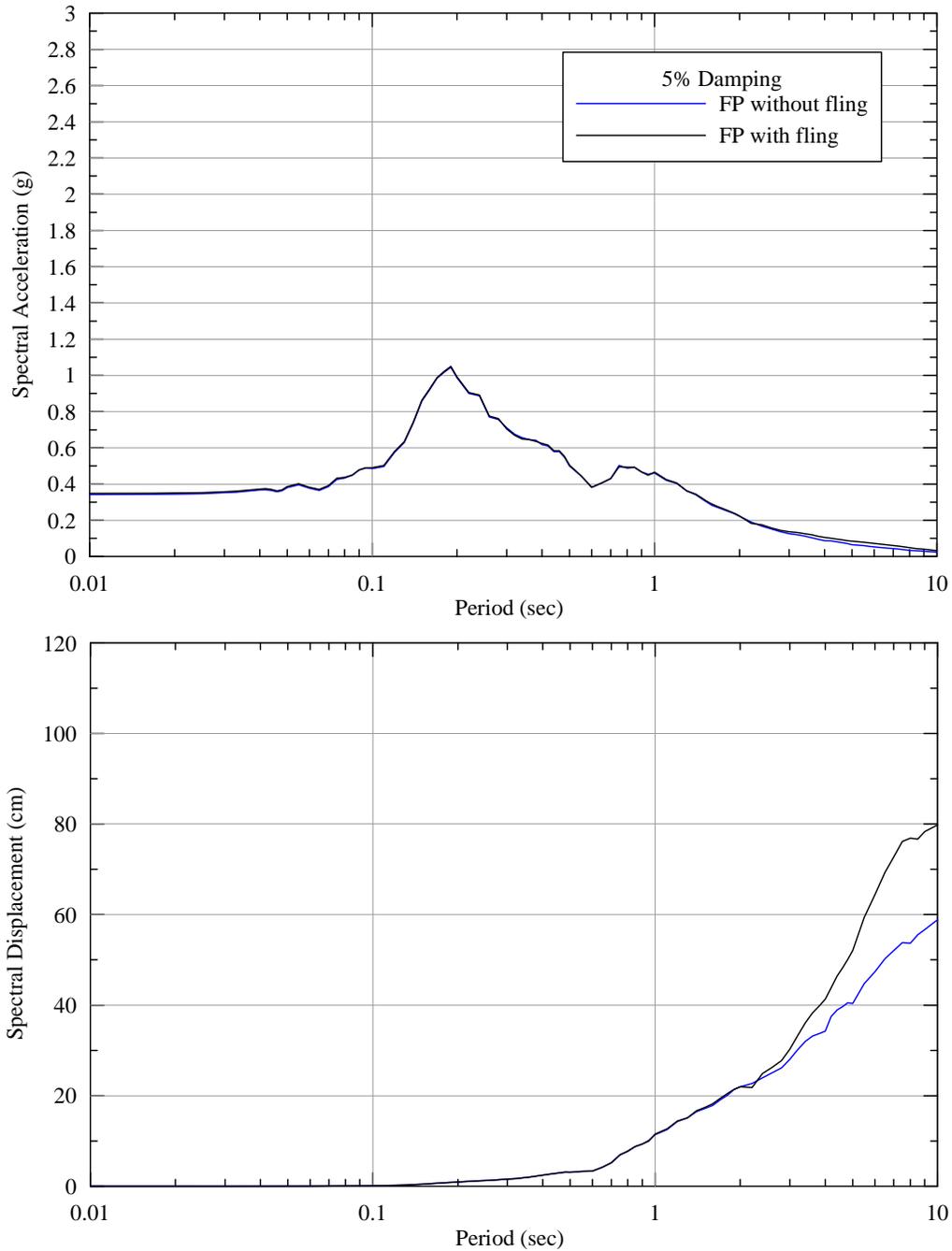


Figure 184: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at invert of the tunnel, 1999 Chi-Chi Earthquake

RW8-R1 PROFILE (RETAINING WALL AREA)

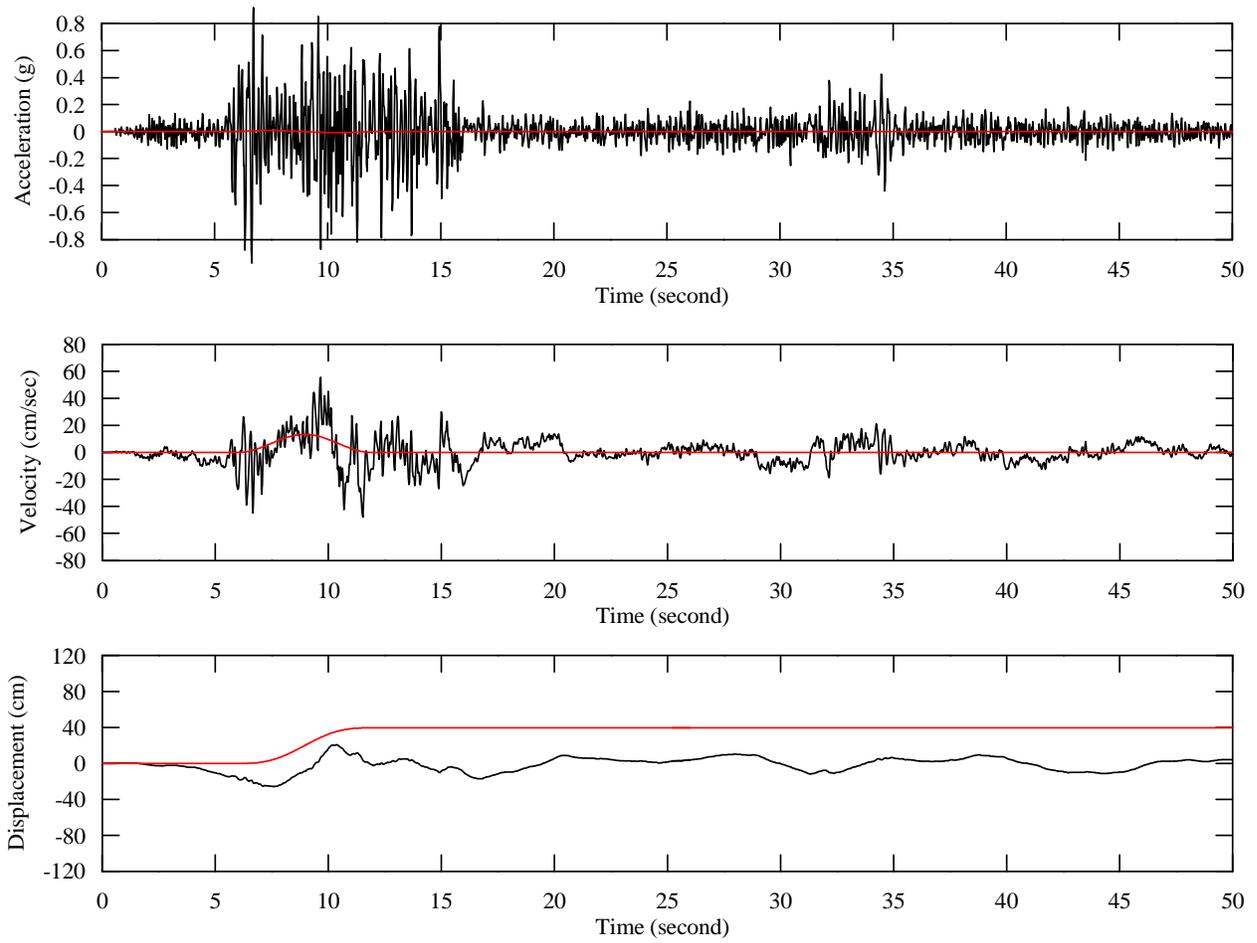


Figure 185: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1990 Manjil Earthquake

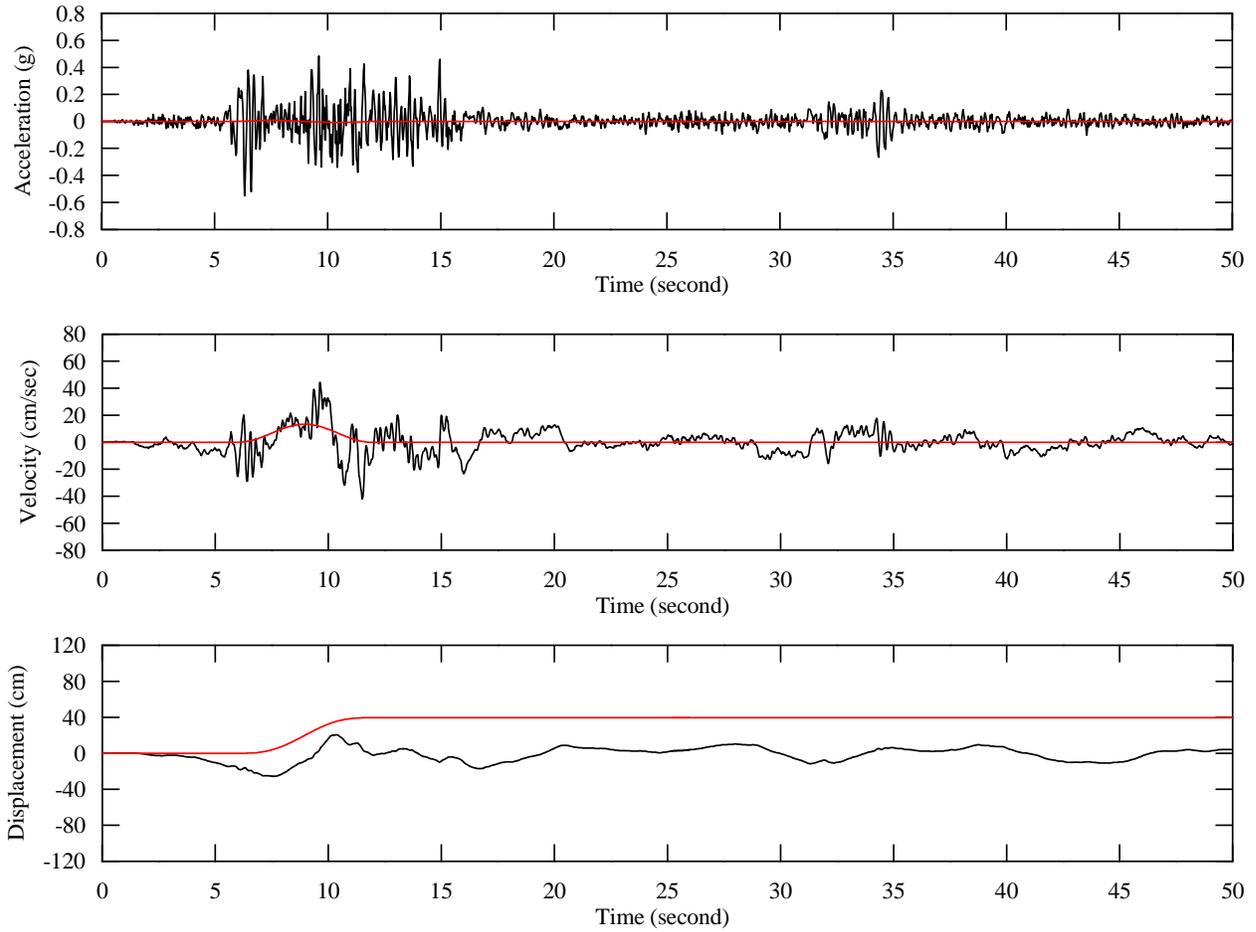


Figure 186: Fault parallel time histories at bottom of retaining wall from site response analysis and fling time histories, 1990 Manjil Earthquake

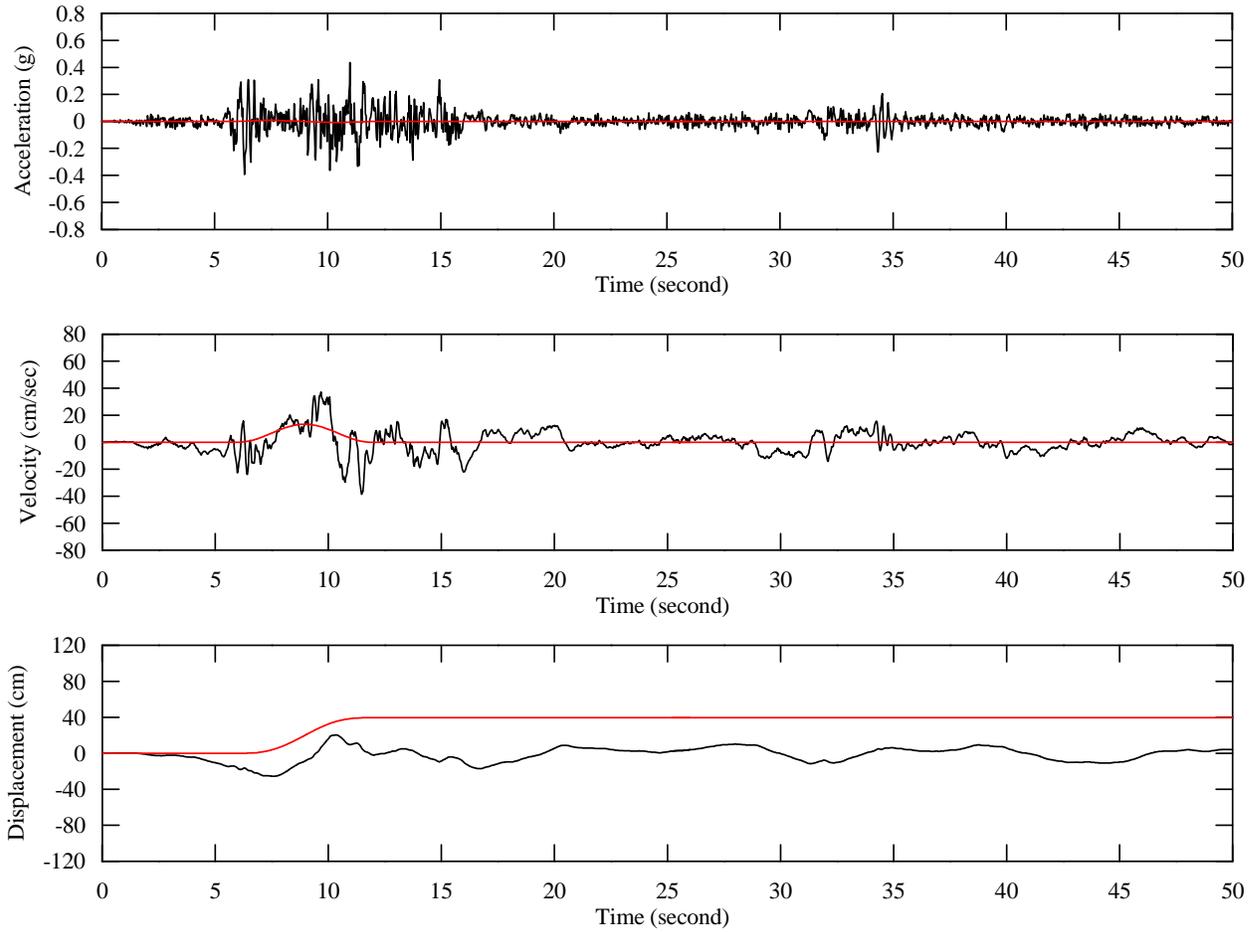


Figure 187: Fault parallel time histories at 20ft below bottom of retaining wall from site response analysis and fling time histories, 1990 Manjil Earthquake

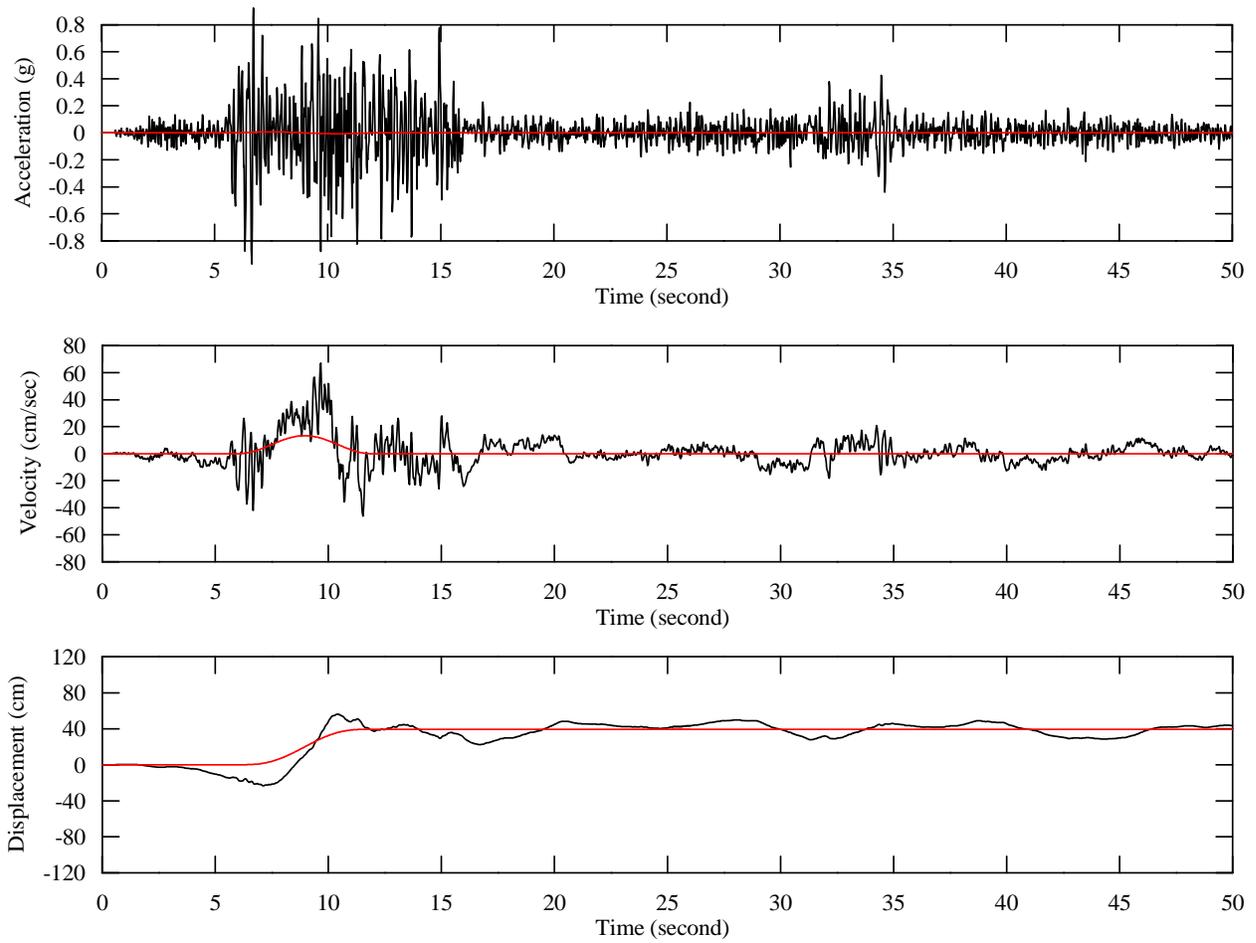


Figure 188: Fault parallel time histories including fling at ground surface, 1990 Manjil Earthquake

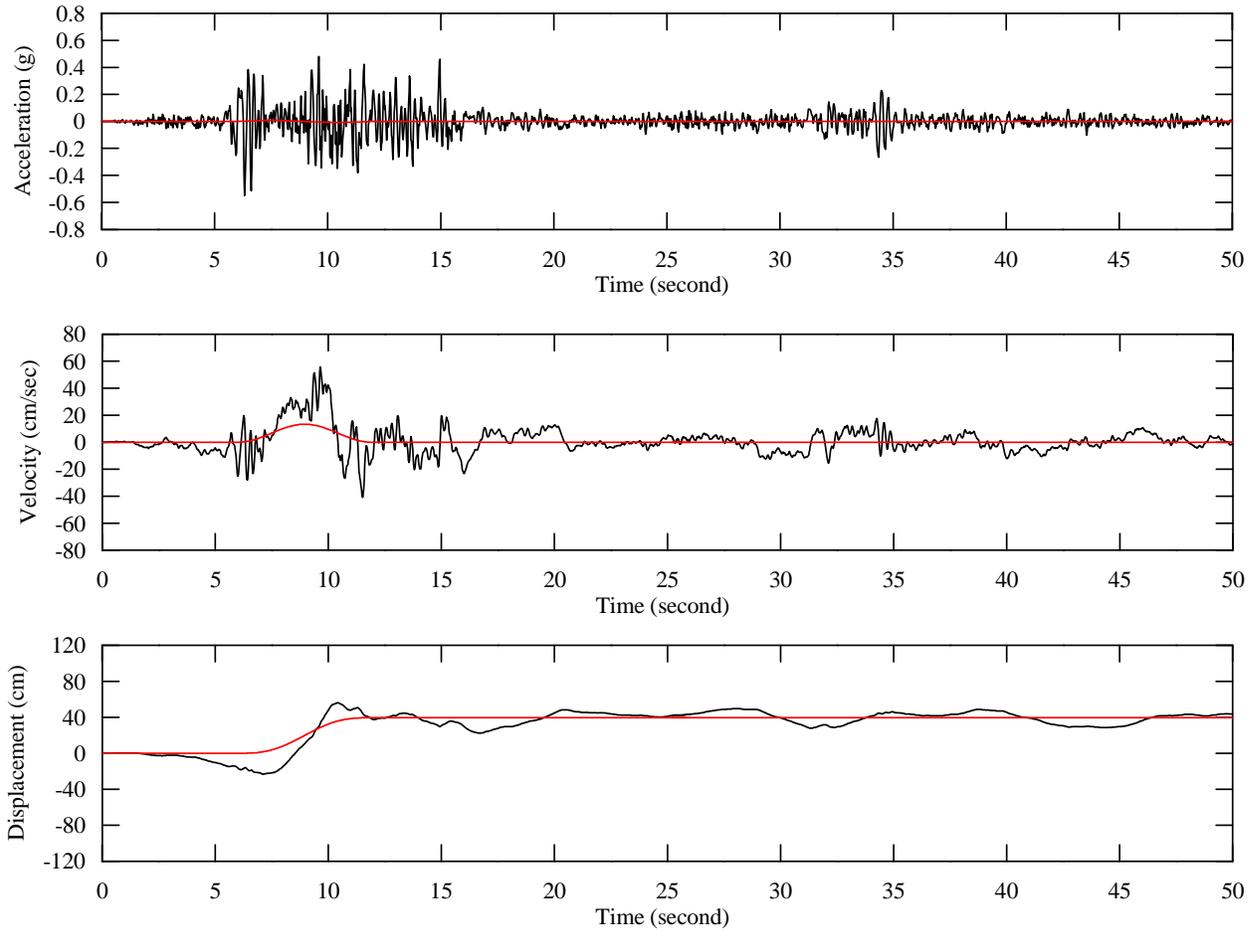


Figure 189: Fault parallel time histories including fling at the bottom of retaining wall, 1990 Manjil Earthquake

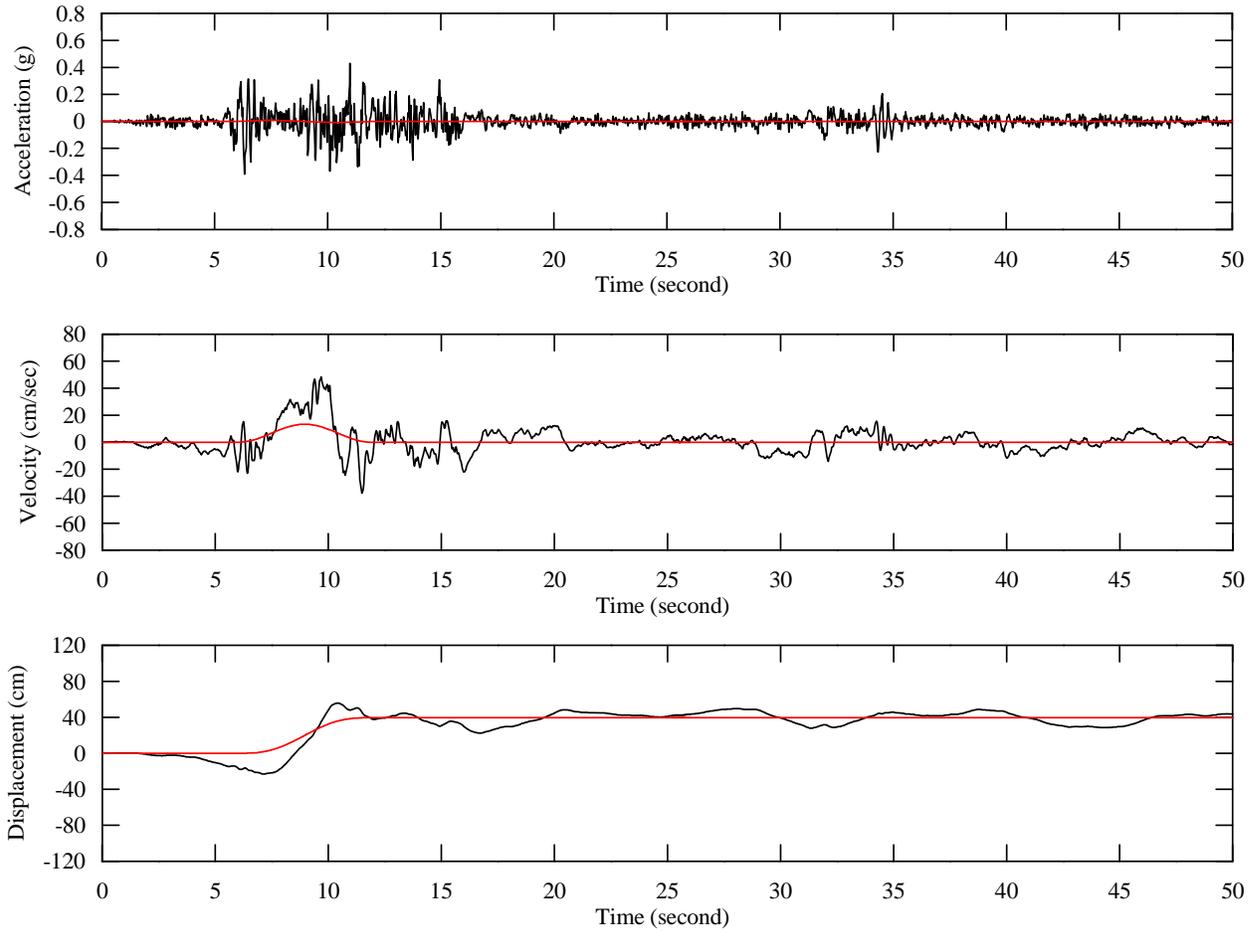


Figure 190: Fault parallel time histories including fling at 20ft below bottom of retaining wall, 1990 Manjil Earthquake

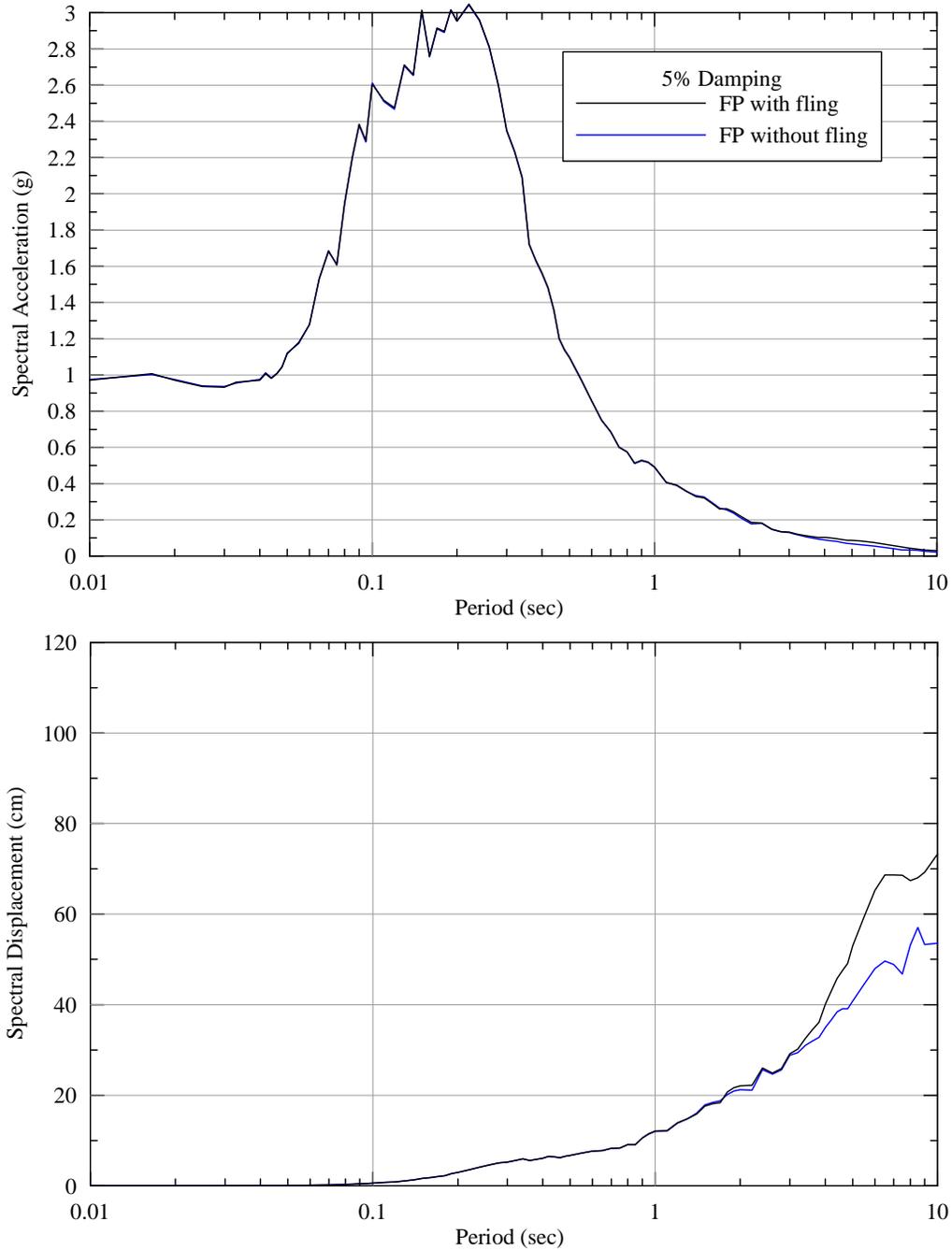


Figure 191: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1990 Manjil Earthquake

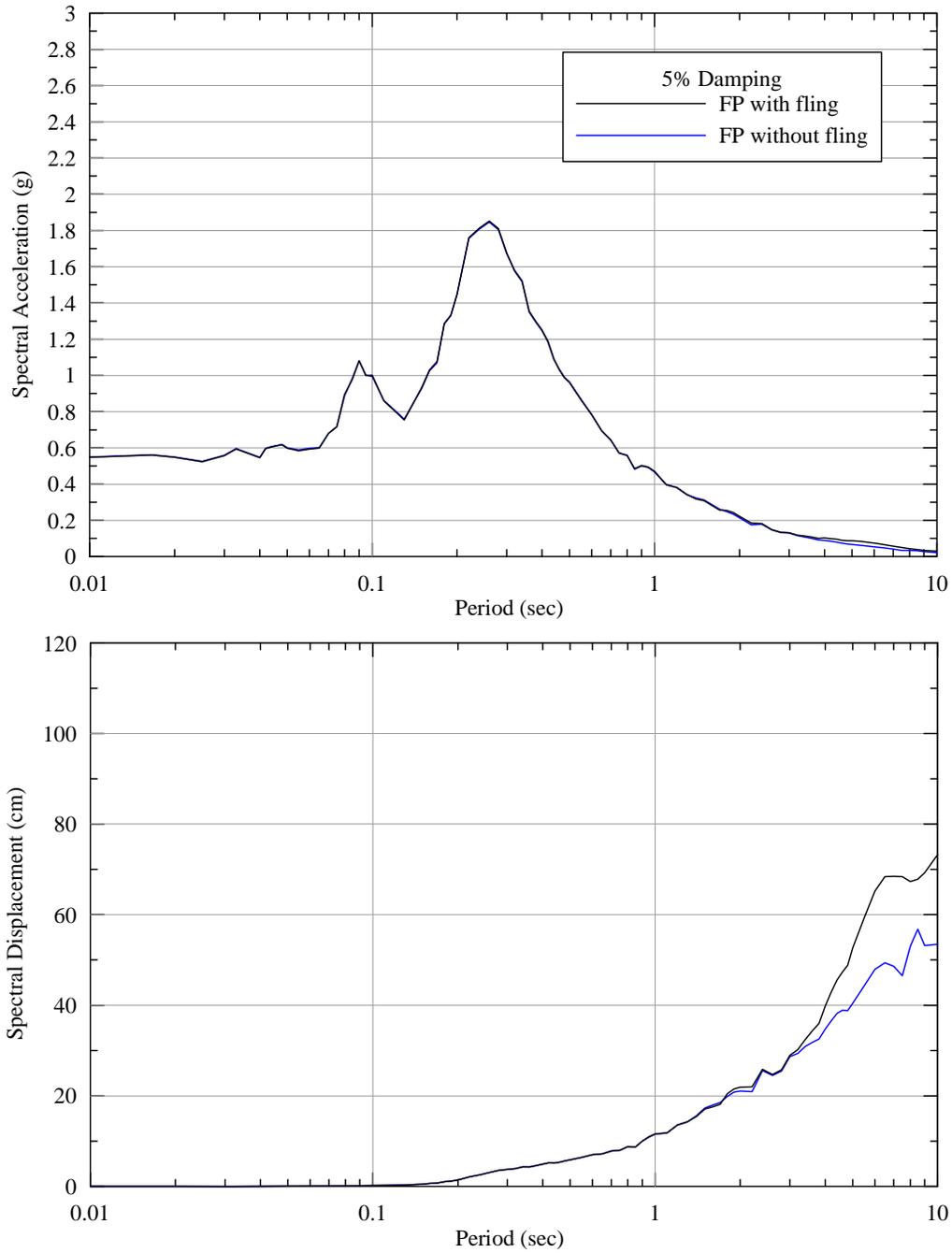


Figure 192: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at the bottom of retaining wall, 1990 Manjil Earthquake

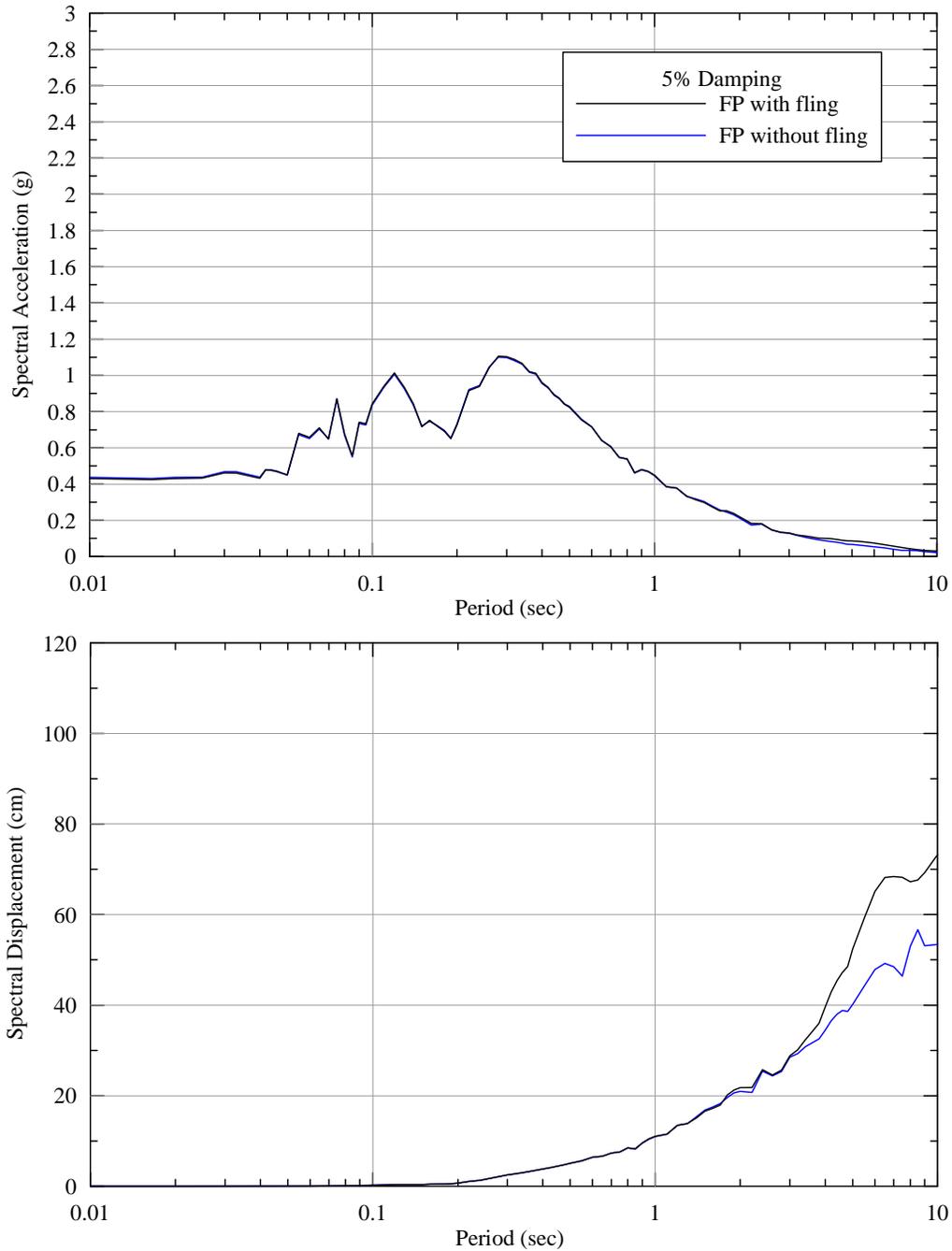


Figure 193: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at 20ft below bottom of retaining wall, 1990 Manjil Earthquake

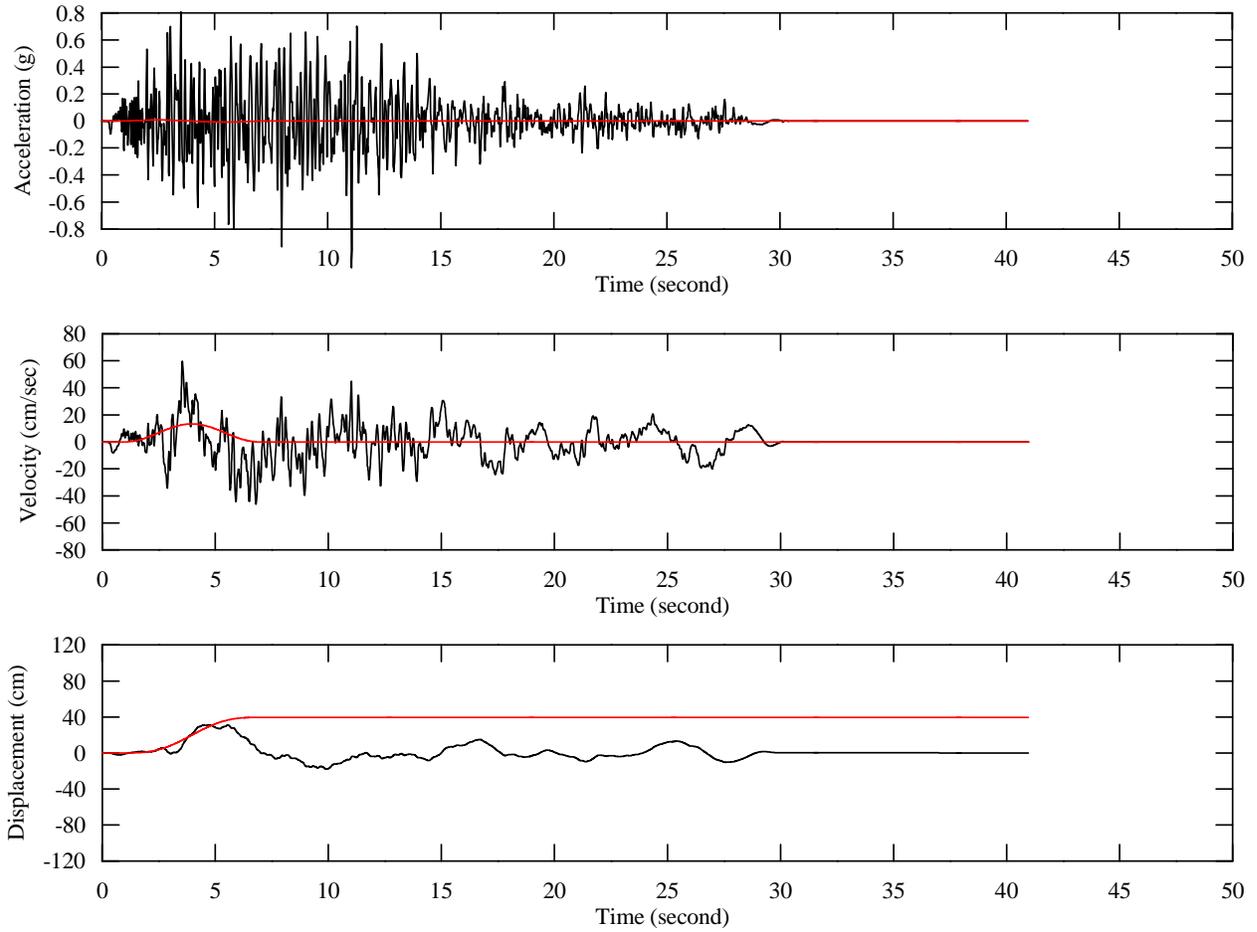


Figure 194: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1999 Kocaeli Earthquake

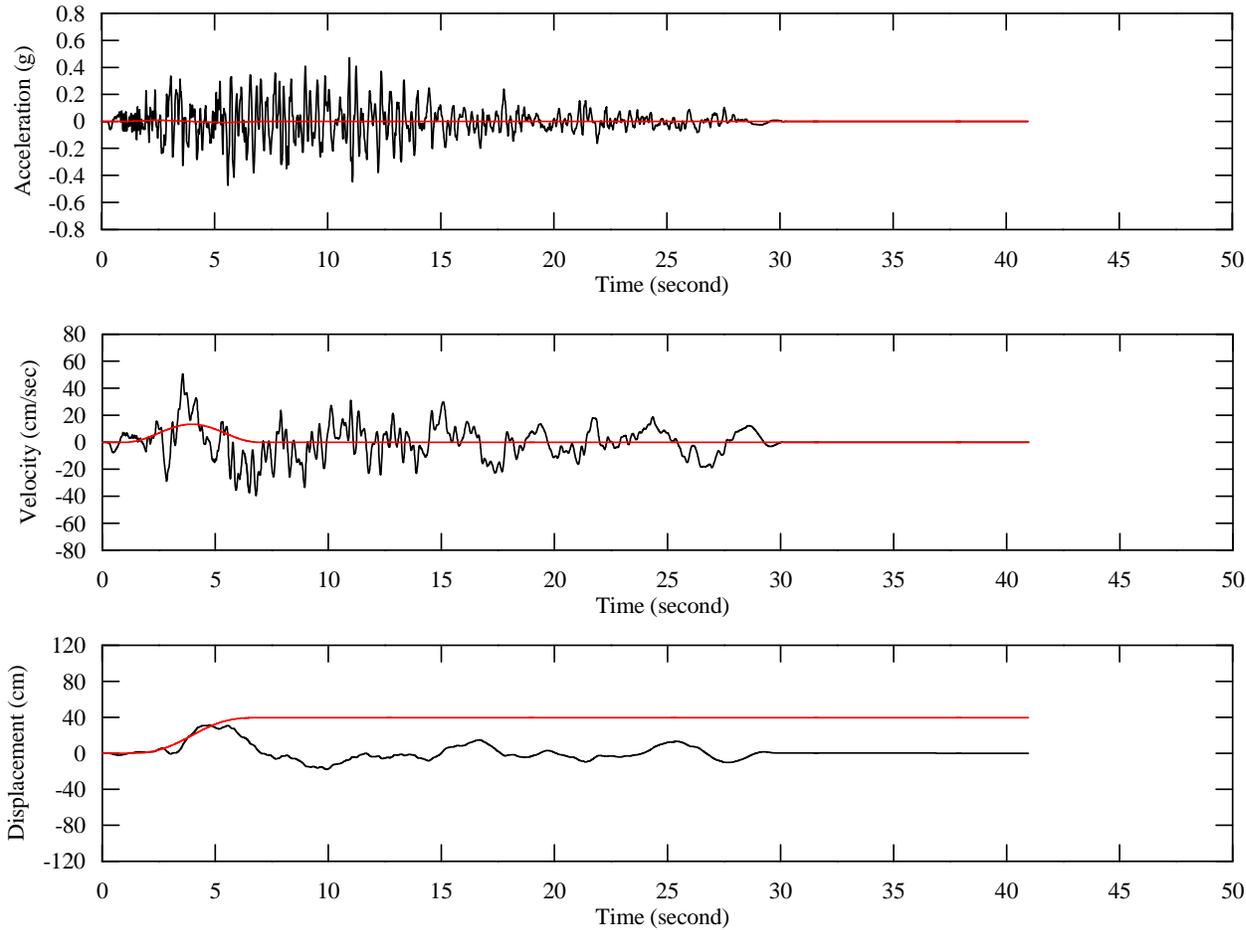


Figure 195: Fault parallel time histories at the bottom of retaining wall from site response analysis and fling time histories, 1999 Kocaeli Earthquake

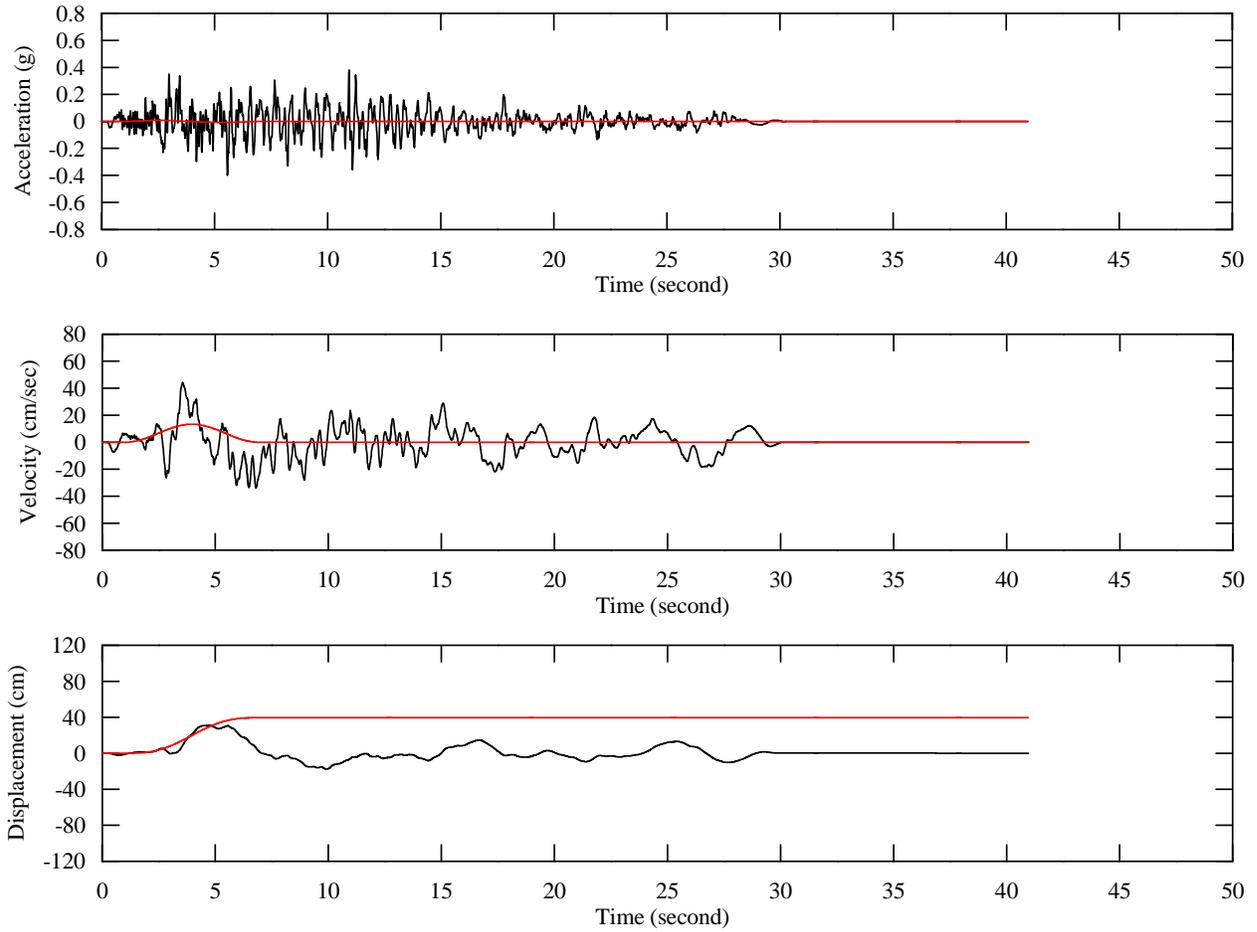


Figure 196: Fault parallel time histories at 20ft below bottom of retaining wall from site response analysis and fling time histories, 1999 Kocaeli Earthquake

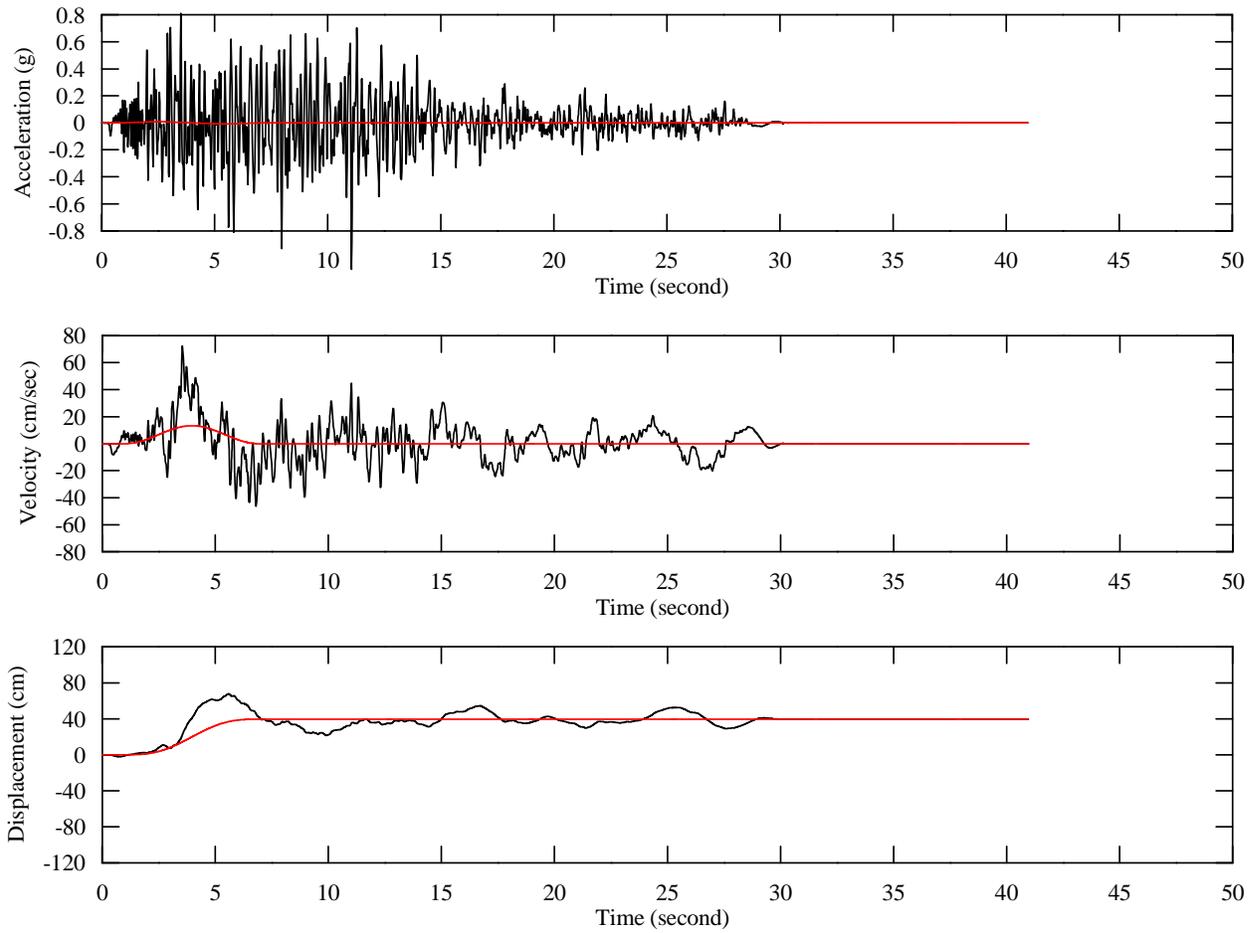


Figure 197: Fault parallel time histories including fling at ground surface, 1999 Kocaeli Earthquake

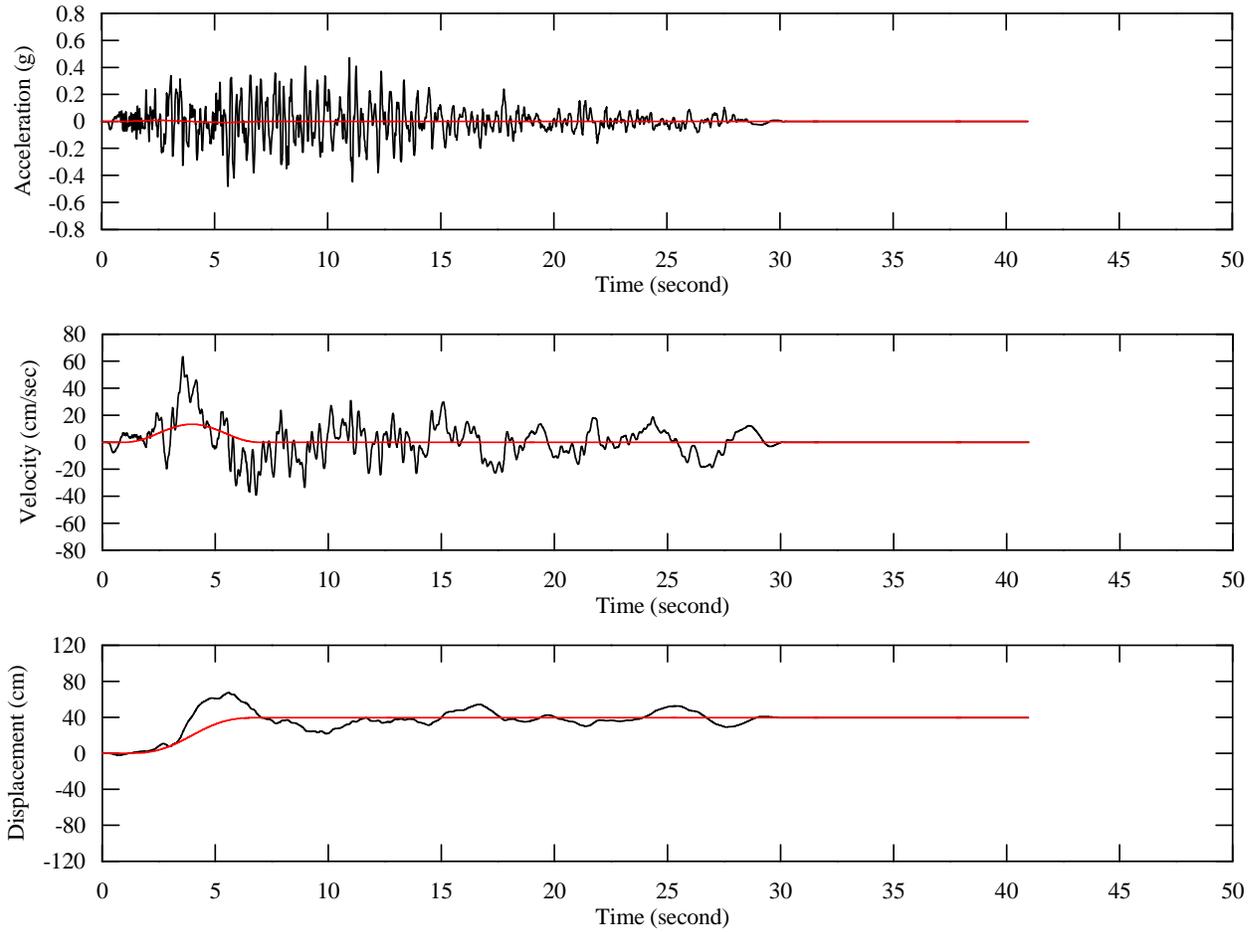


Figure 198: Fault parallel time histories including fling at the bottom of retaining wall, 1999 Kocaeli Earthquake

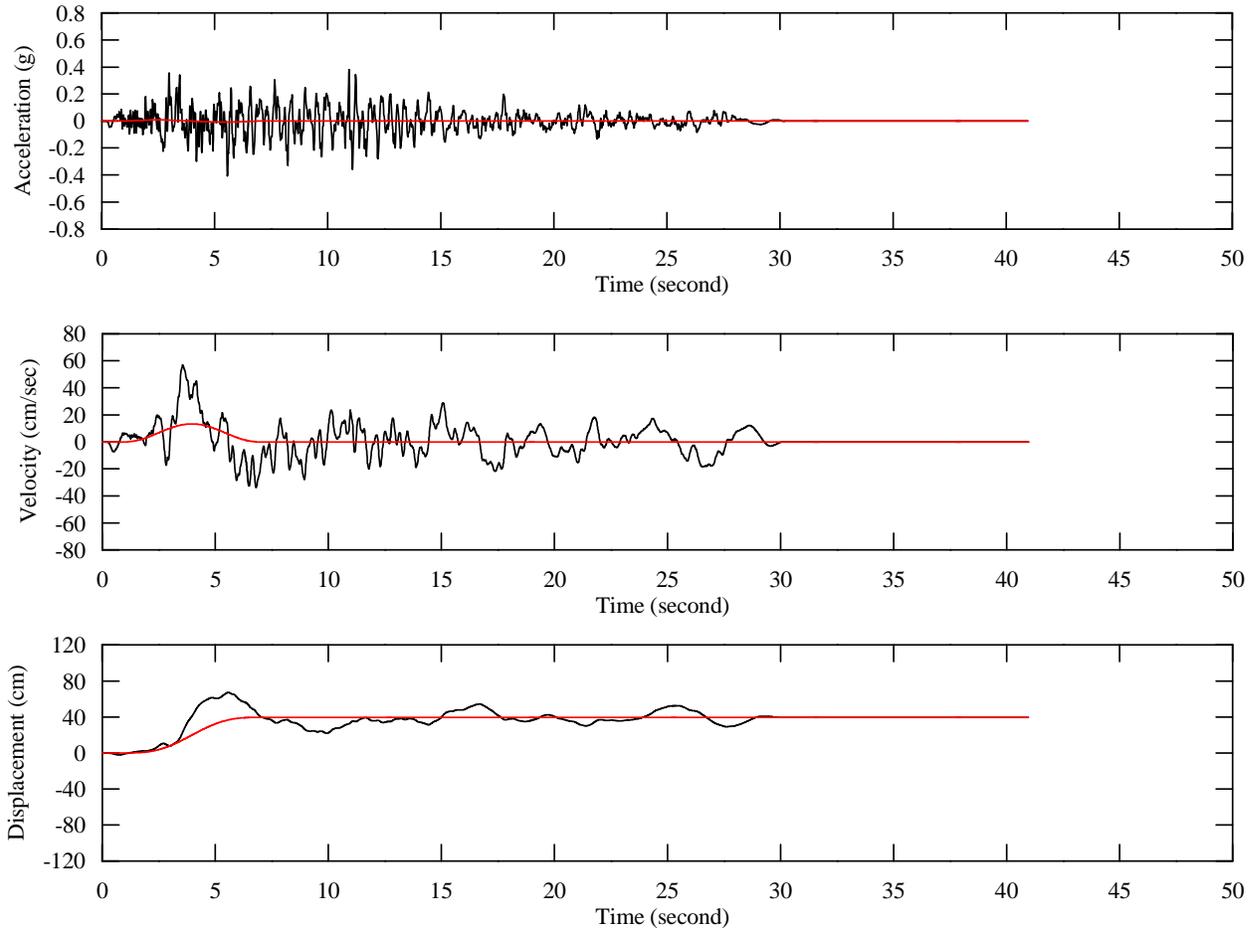


Figure 199: Fault parallel time histories including fling at 20ft below bottom of retaining wall, 1999 Kocaeli Earthquake

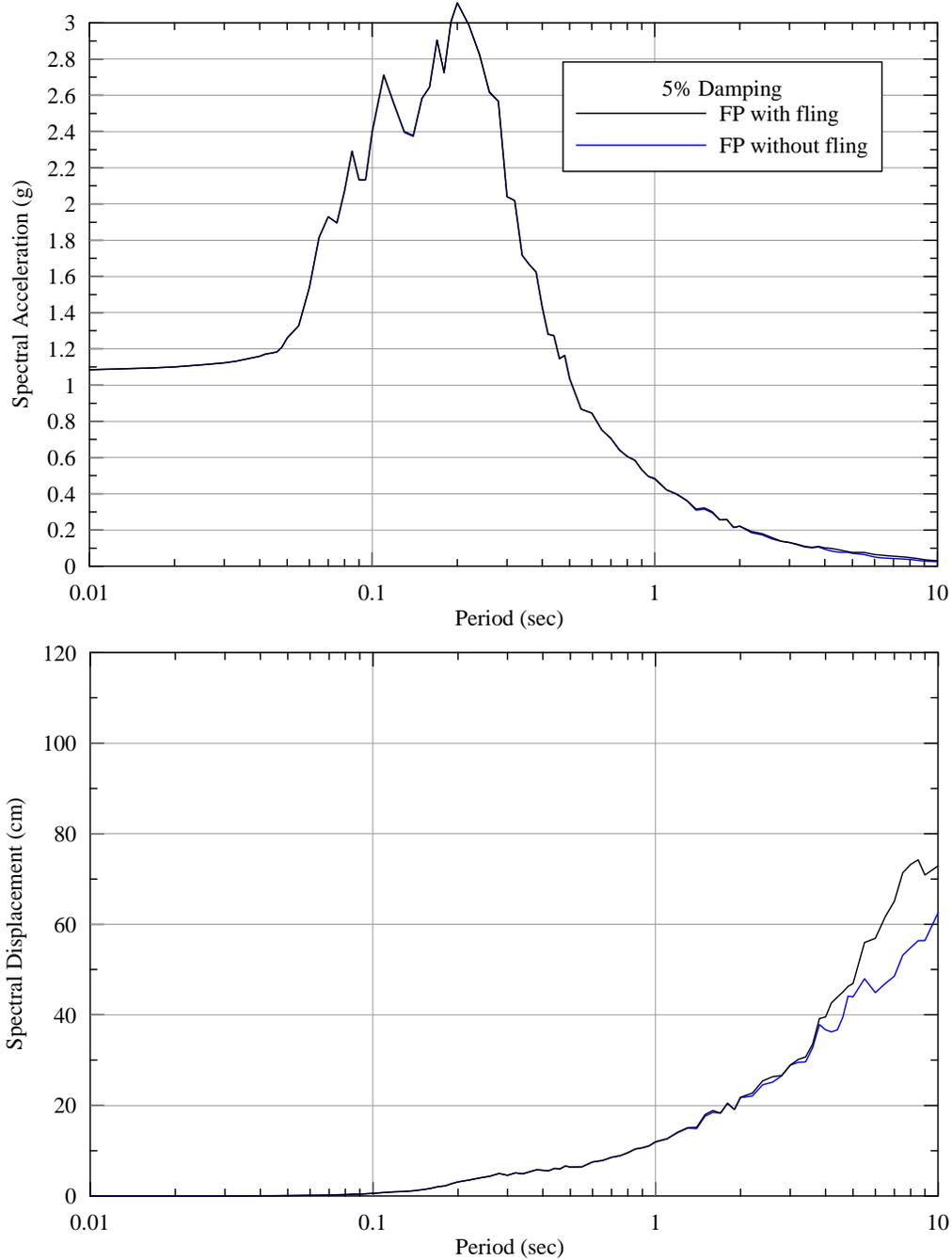


Figure 200: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1999 Kocaeli Earthquake

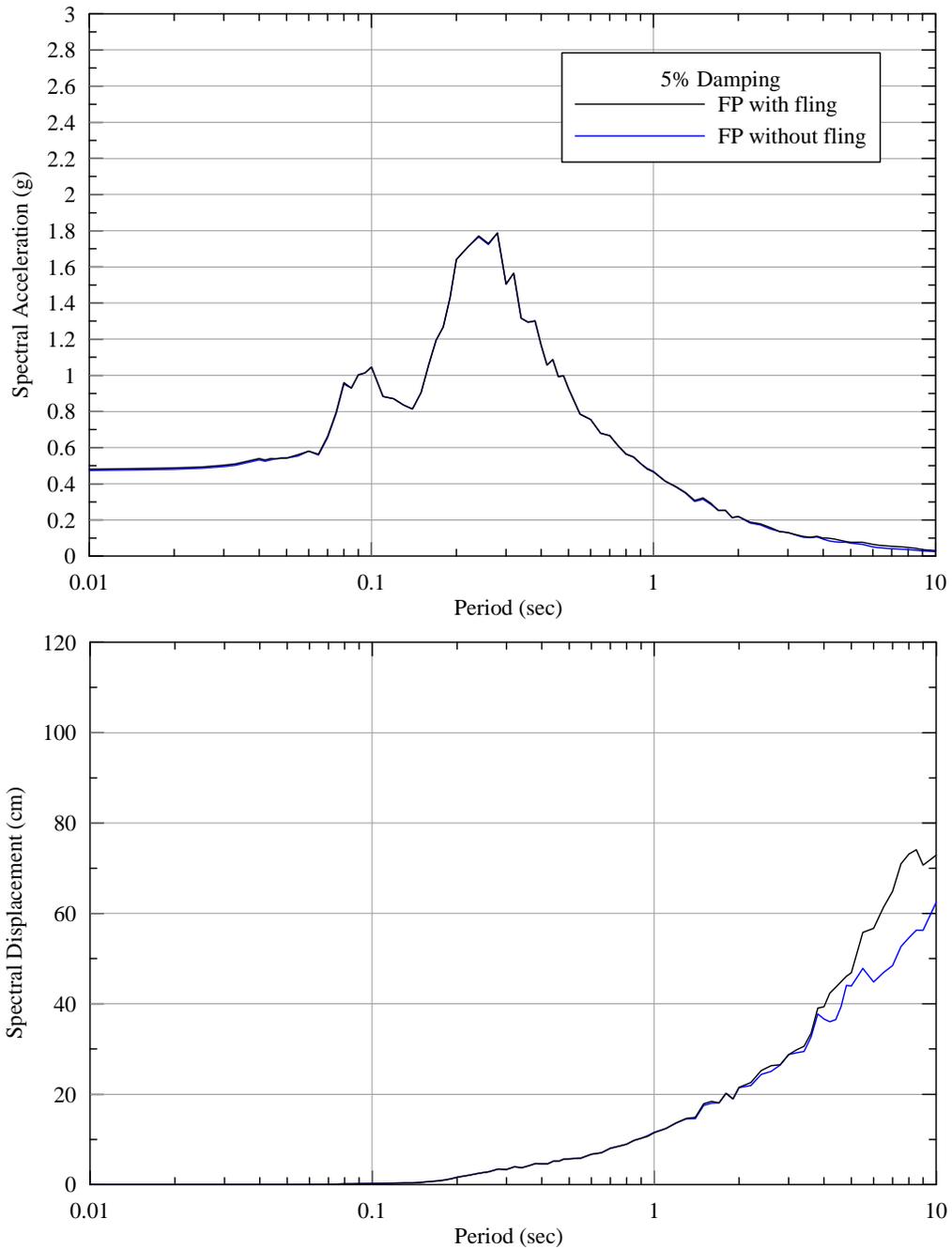


Figure 201: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at the bottom of retaining wall, 1999 Kocaeli Earthquake

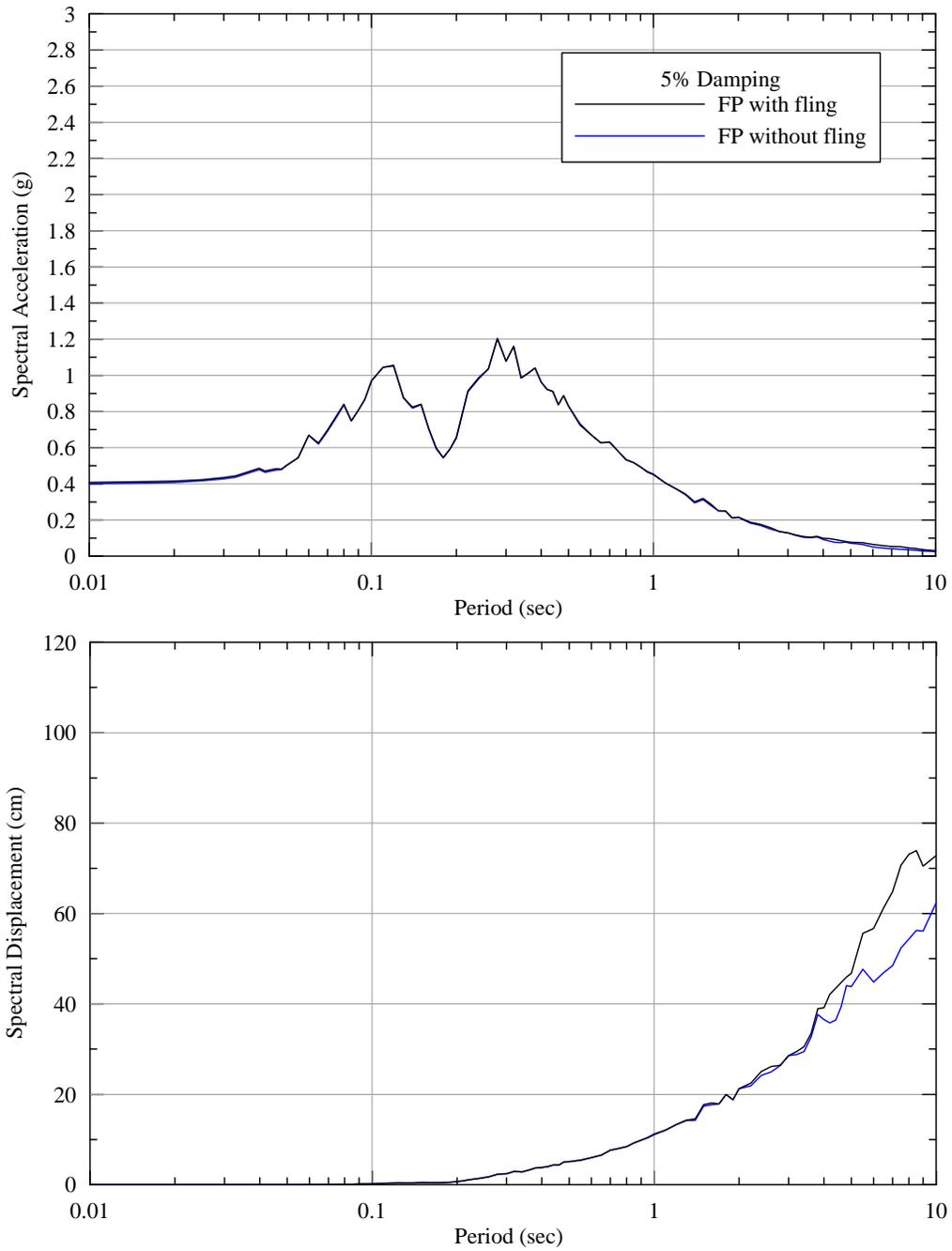


Figure 202: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at 20ft below bottom of retaining wall, 1999 Kocaeli Earthquake

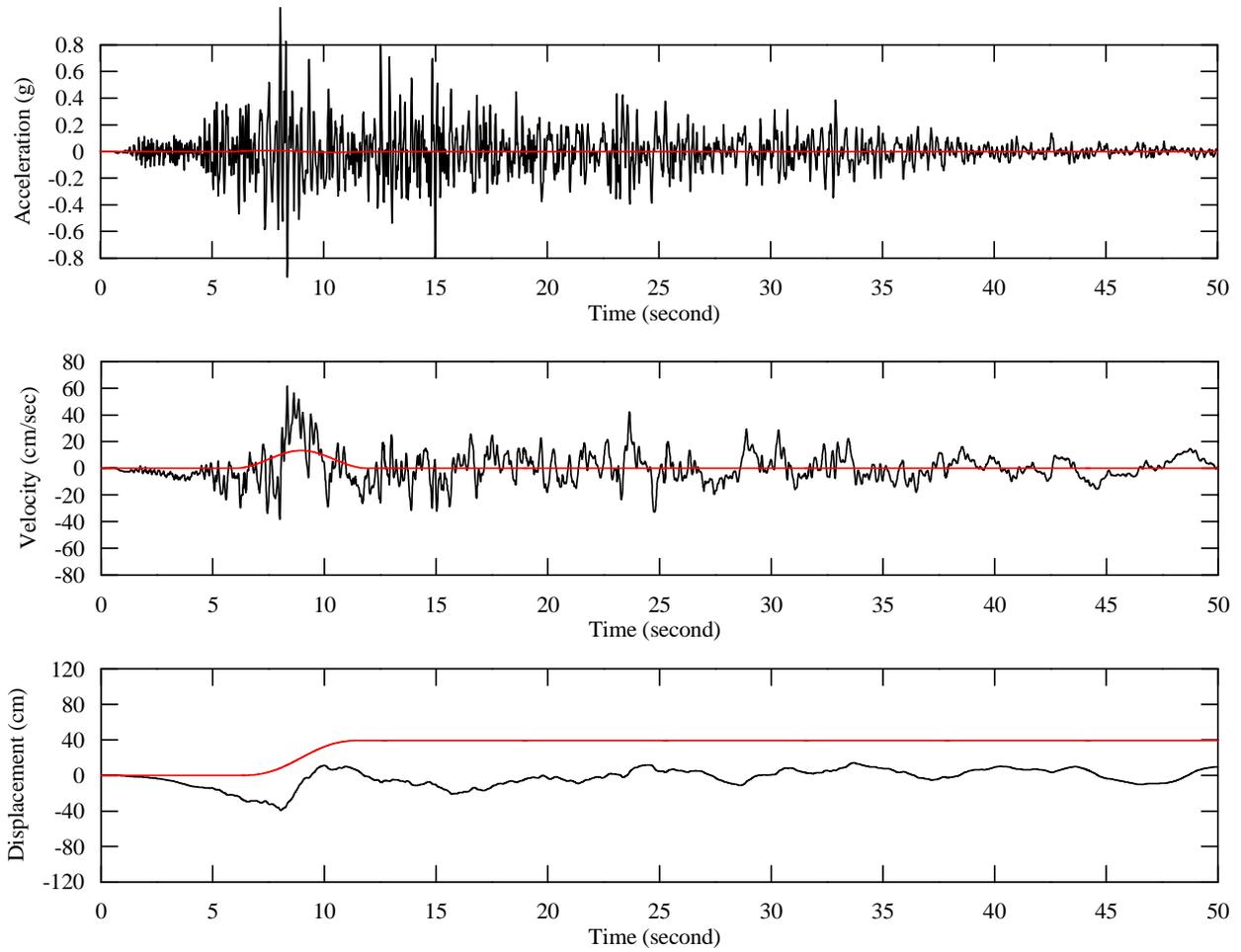


Figure 203: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

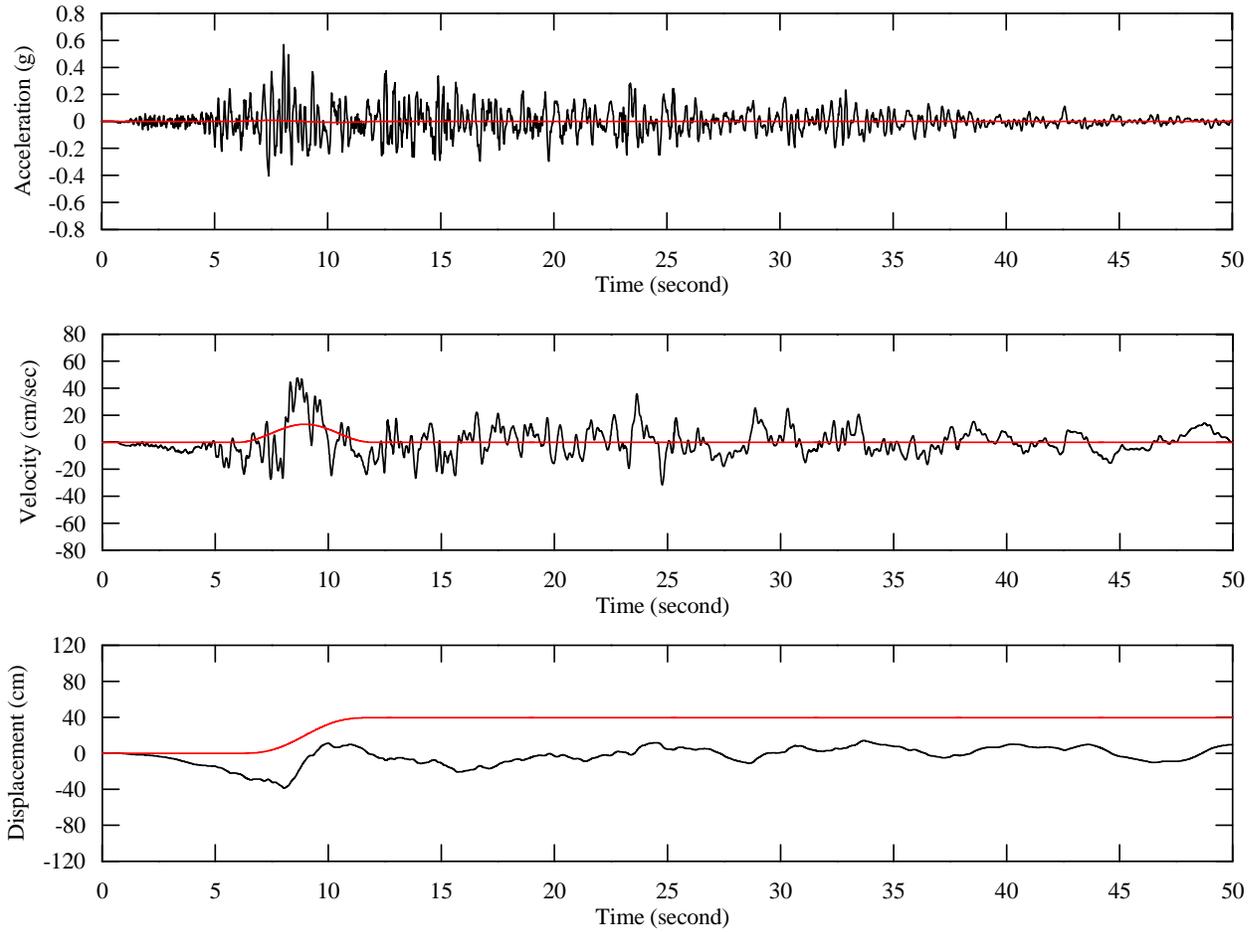


Figure 204: Fault parallel time histories at the bottom of retaining wall from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

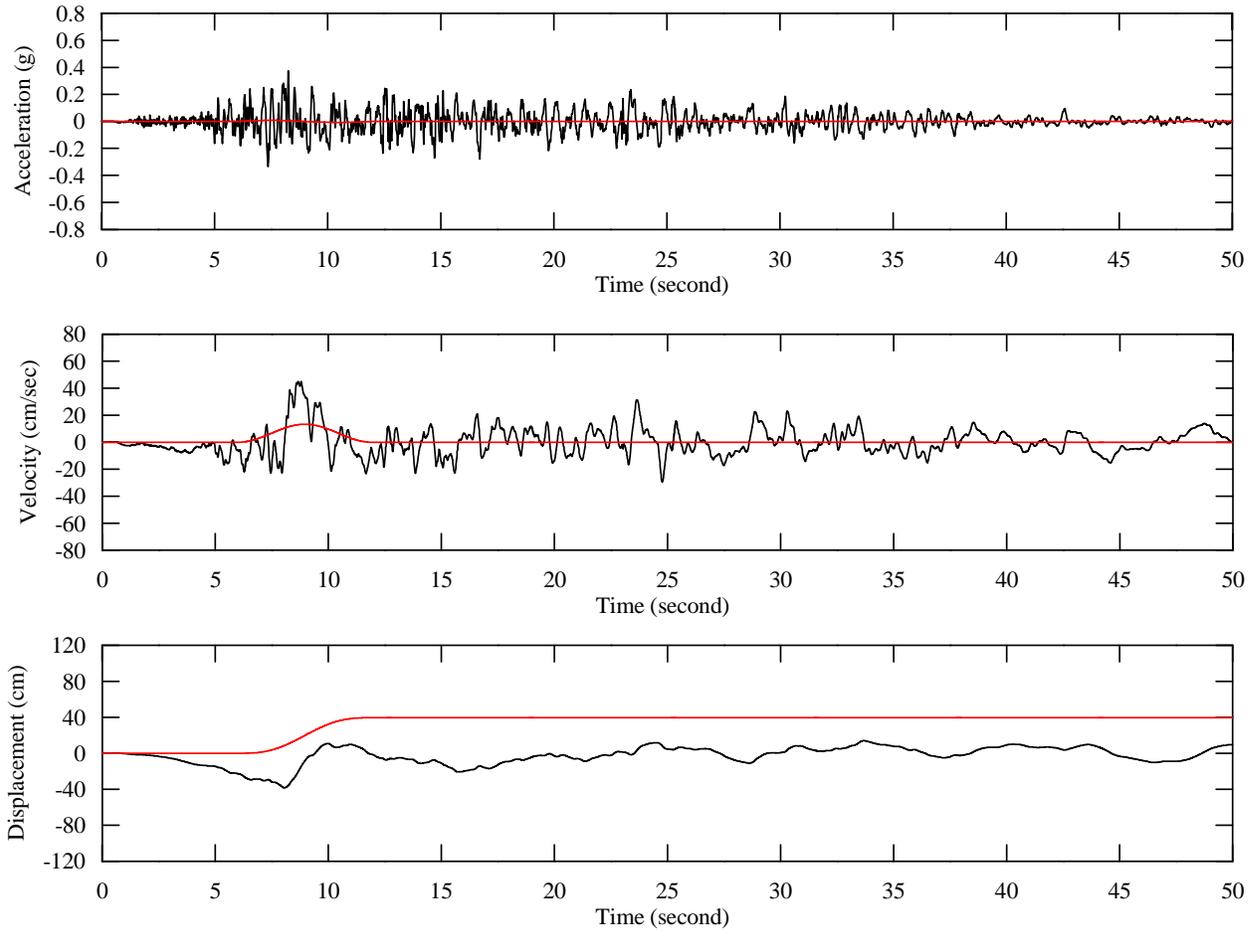


Figure 205: Fault parallel time histories at 20ft below bottom of retaining wall from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

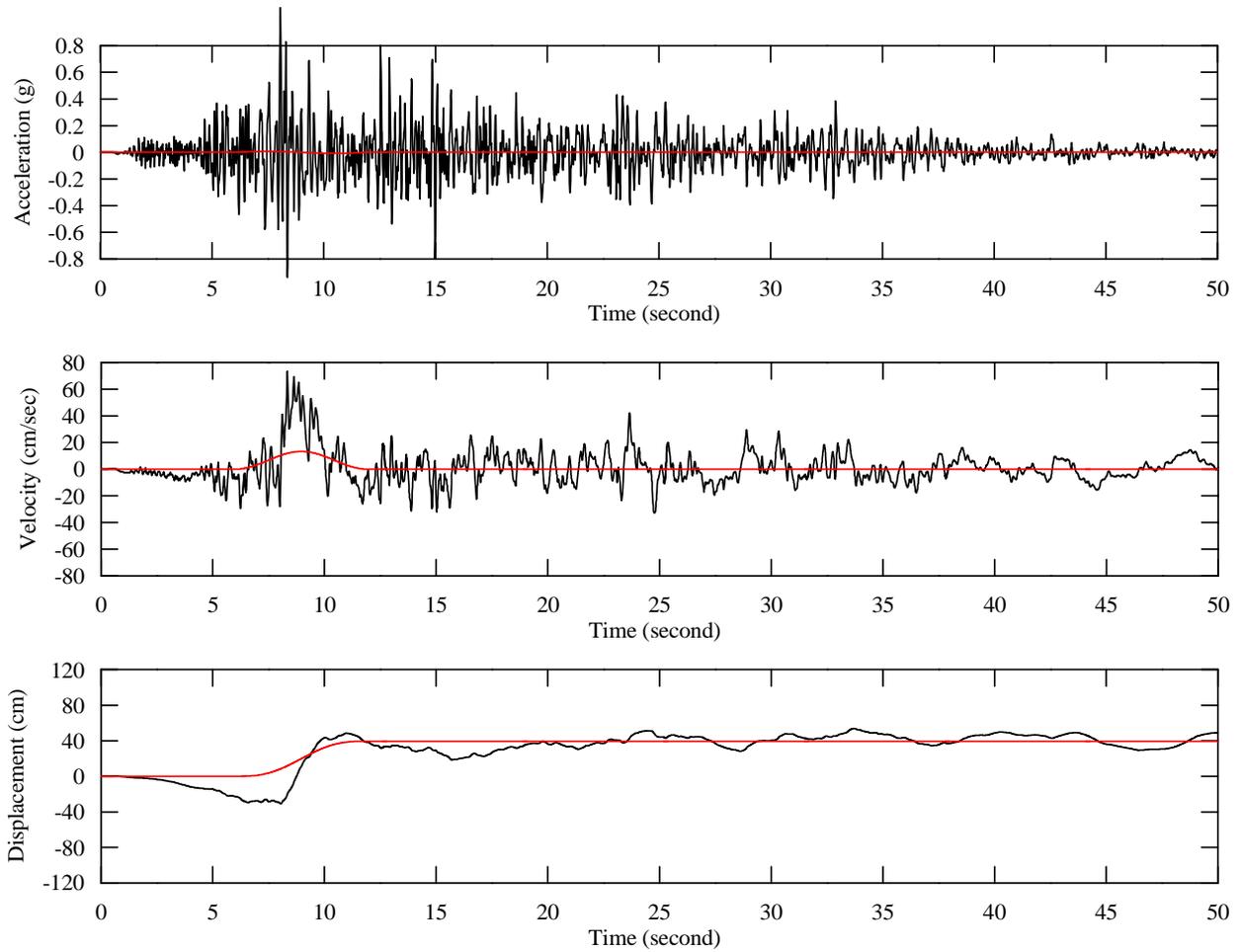


Figure 206: Fault parallel time histories including fling at ground surface, 1999 Chi-Chi Earthquake

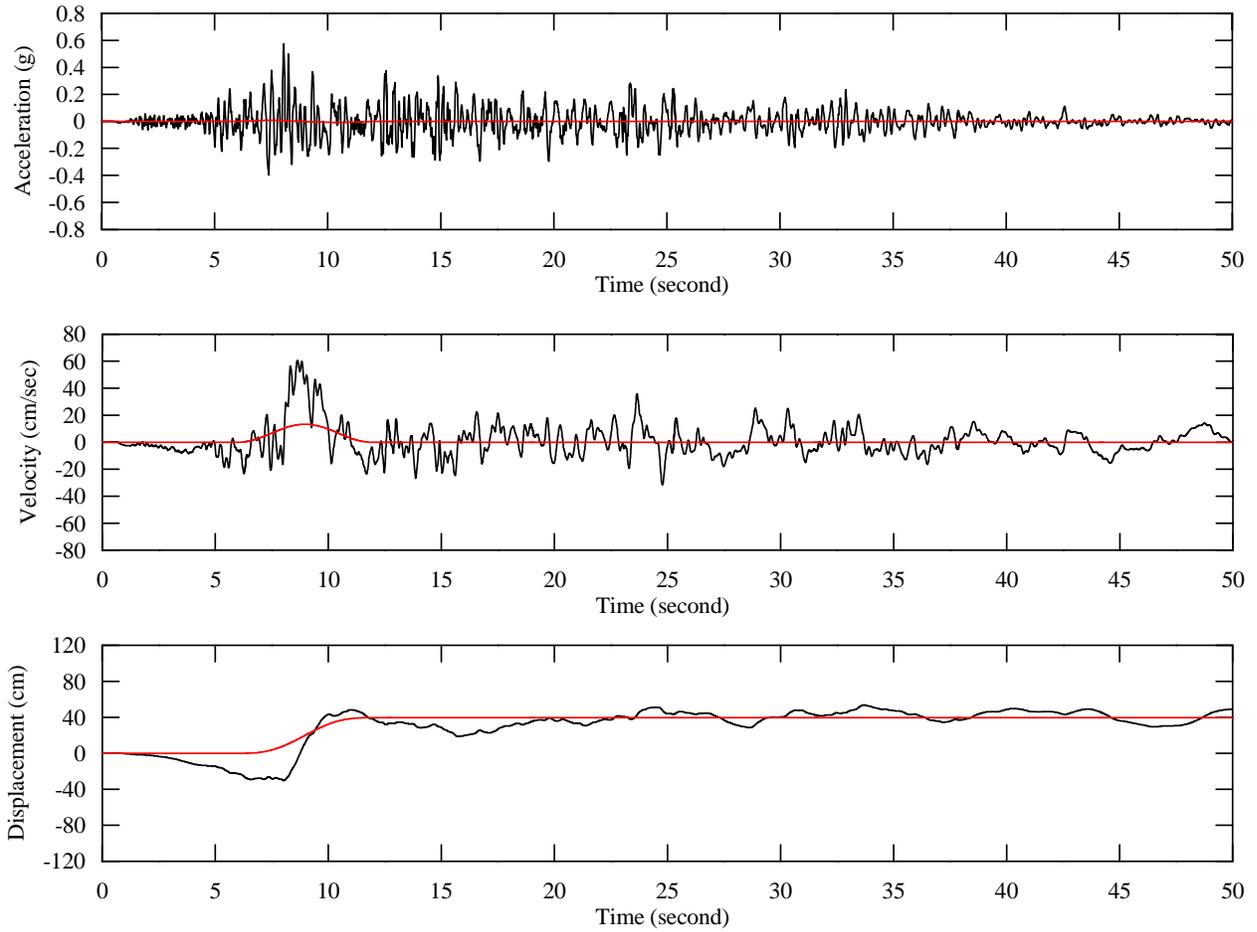


Figure 207: Fault parallel time histories including fling at the bottom of retaining wall, 1999 Chi-Chi Earthquake

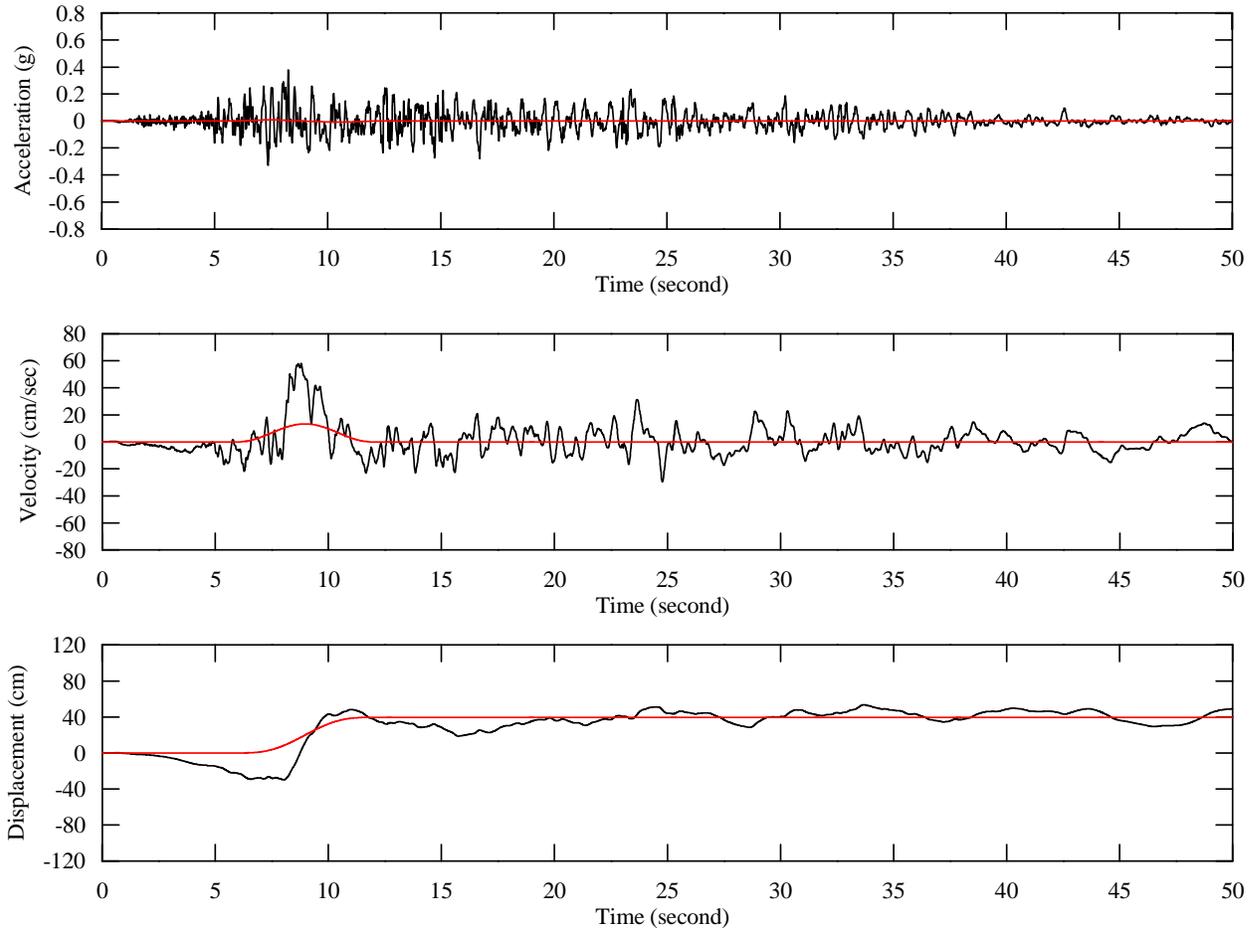


Figure 208: Fault parallel time histories including fling at 20ft below bottom of retaining wall, 1999 Chi-Chi Earthquake

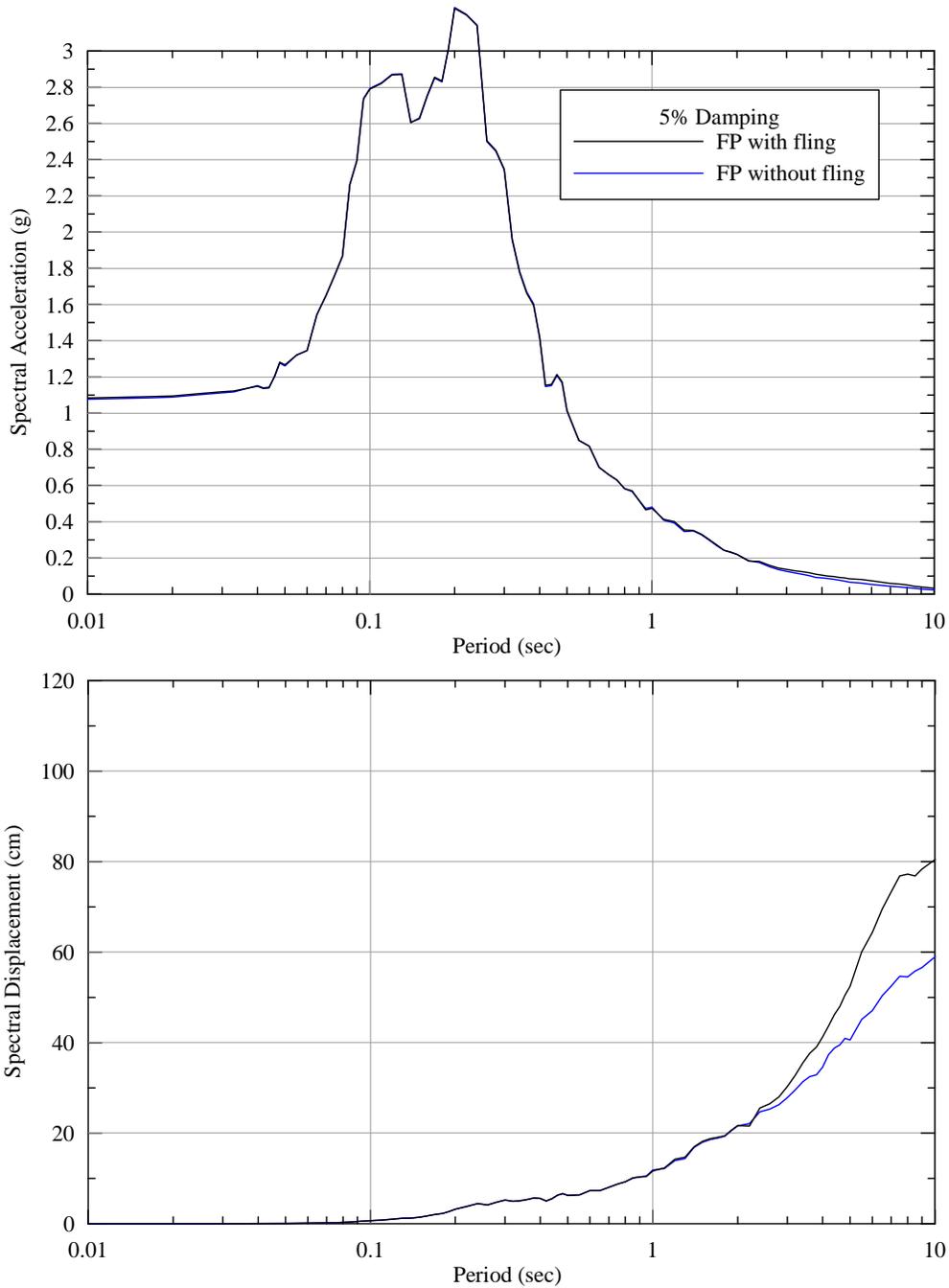


Figure 209: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1999 Chi-Chi Earthquake

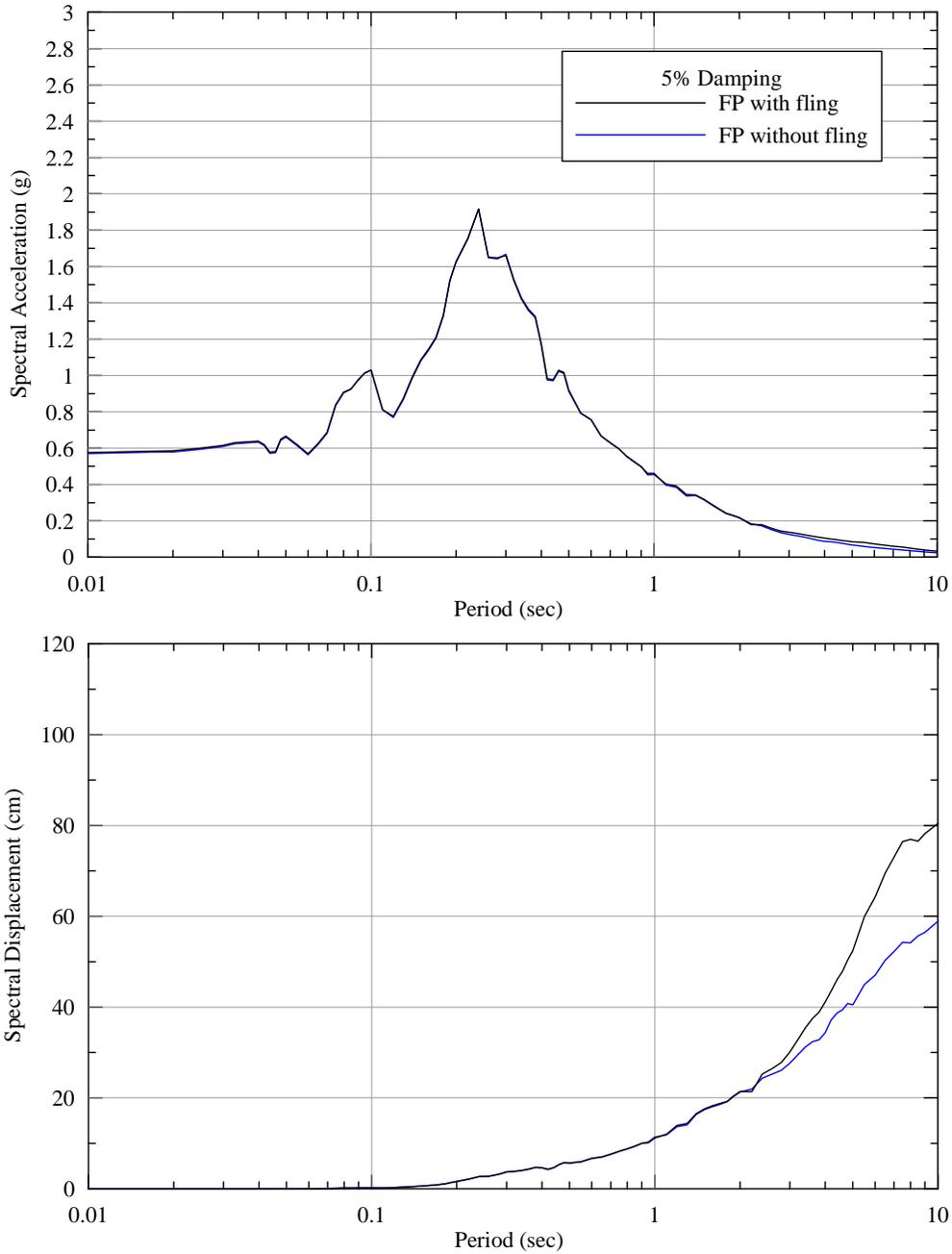


Figure 210: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at the bottom of retaining wall, 1999 Chi- Chi Earthquake

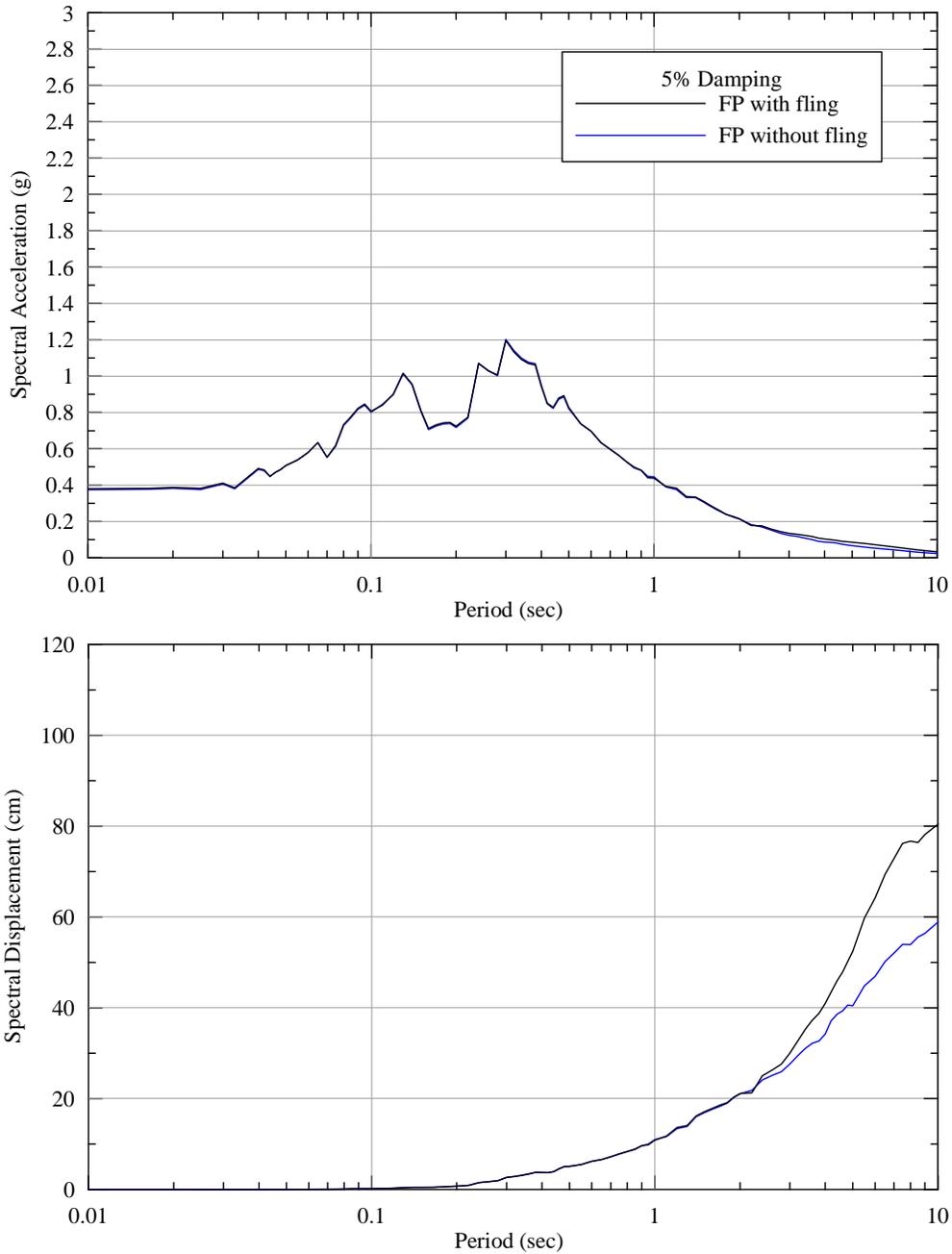


Figure 211: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at 20ft below bottom of retaining wall, 1999 Chi-Chi Earthquake

RW8-R5 PROFILE (RETAINING WALL AREA)

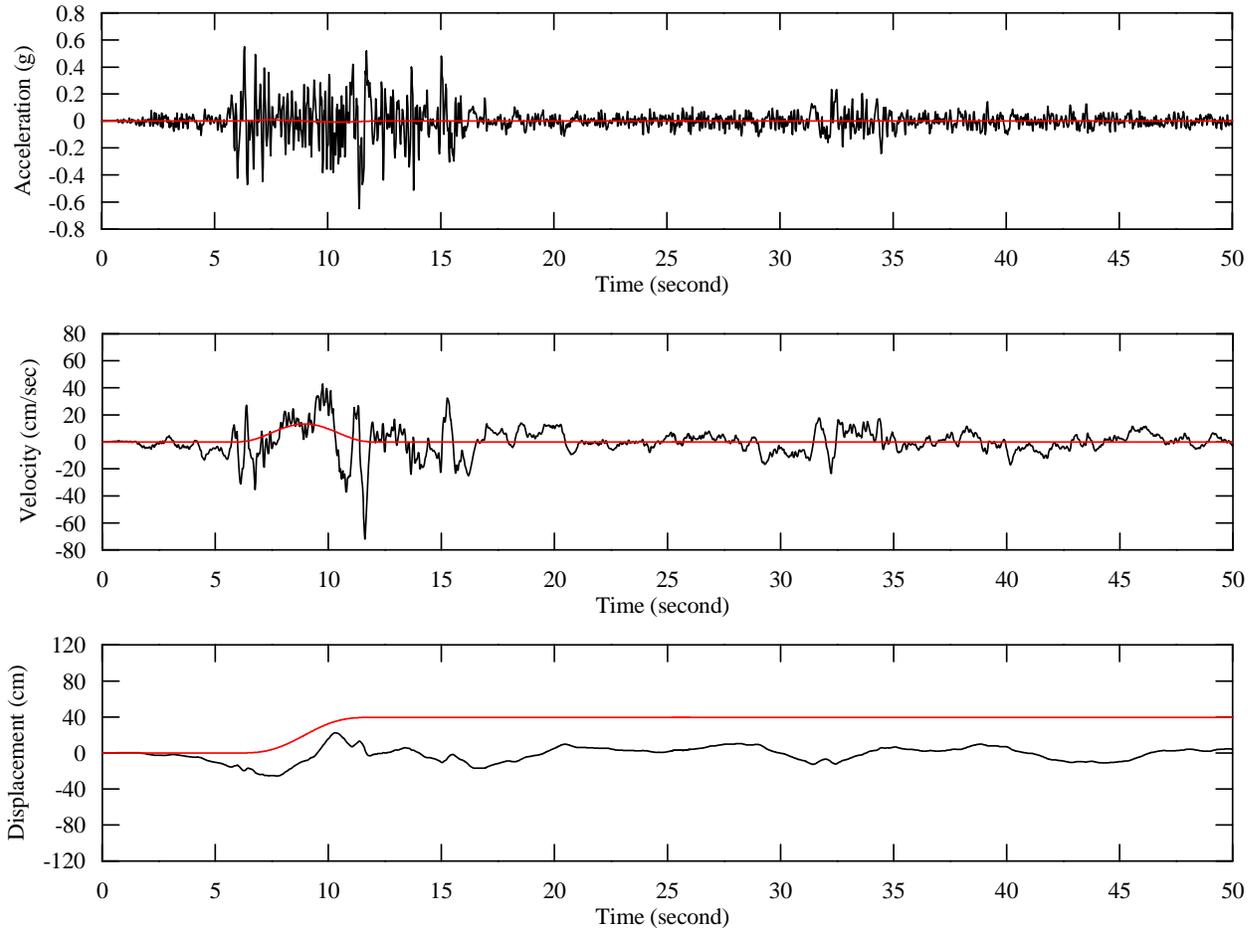


Figure 212: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1990 Manjil Earthquake

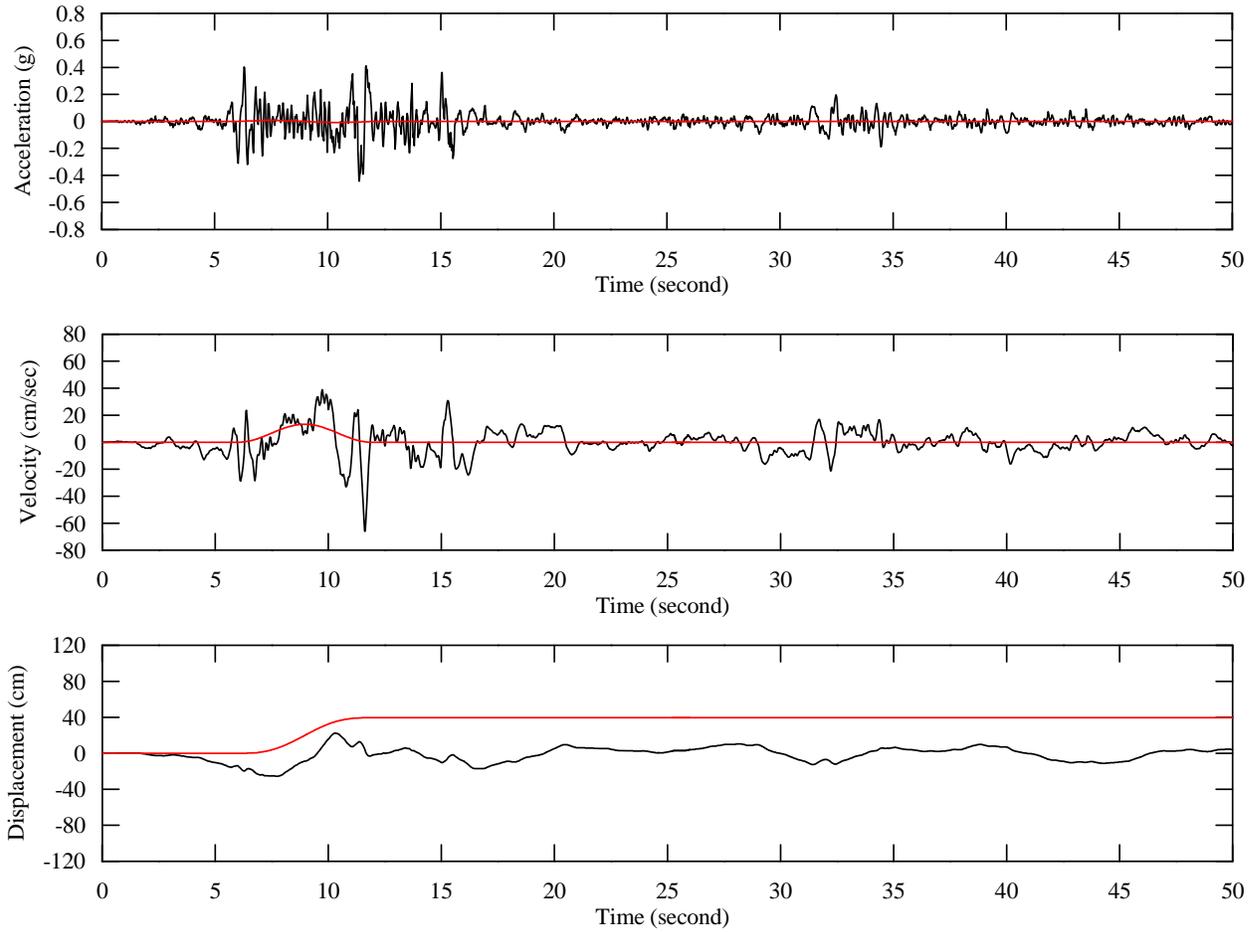


Figure 213: Fault parallel time histories at bottom of retaining wall from site response analysis and fling time histories, 1990 Manjil Earthquake

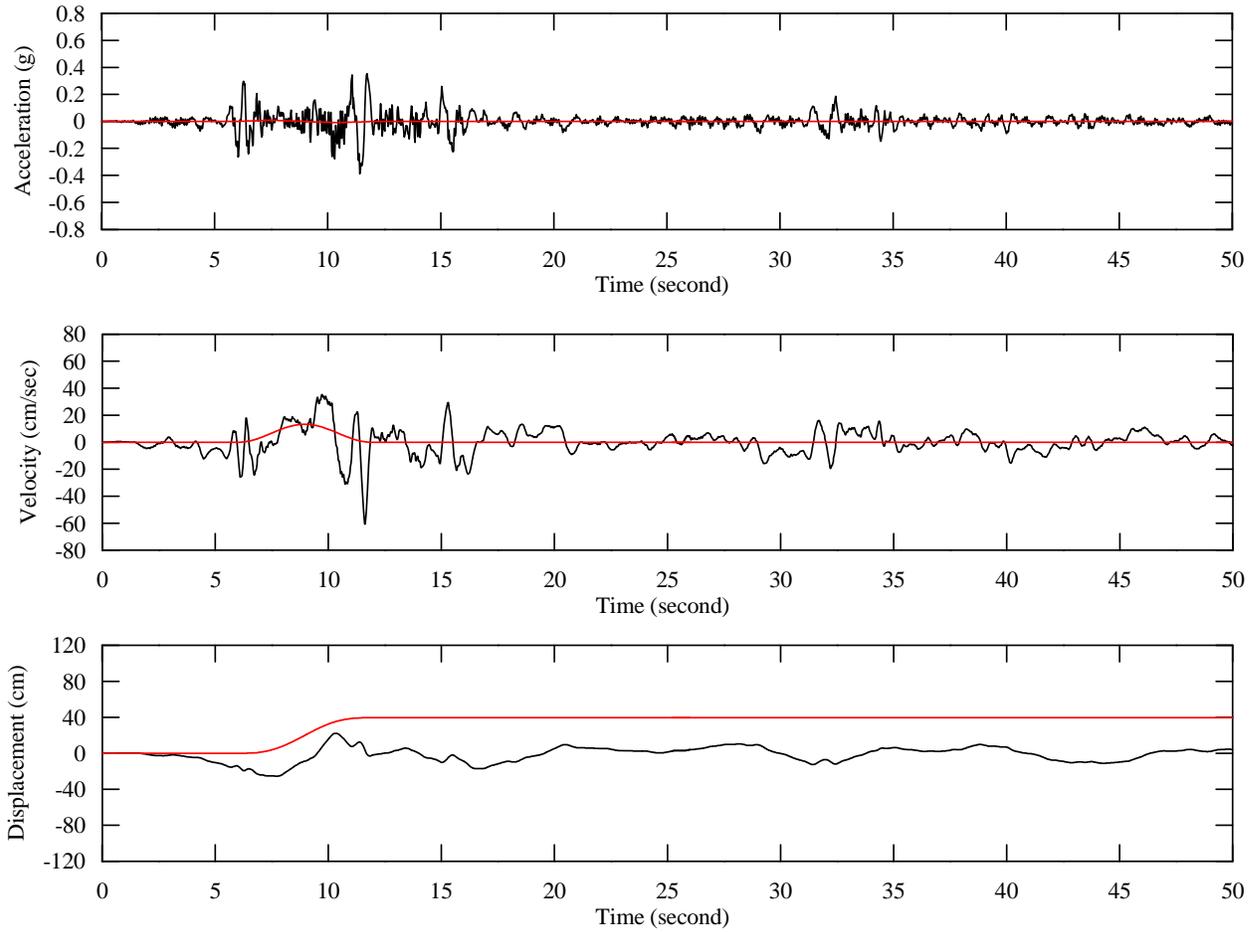


Figure 214: Fault parallel time histories at 20ft below bottom of retaining wall from site response analysis and fling time histories, 1990 Manjil Earthquake

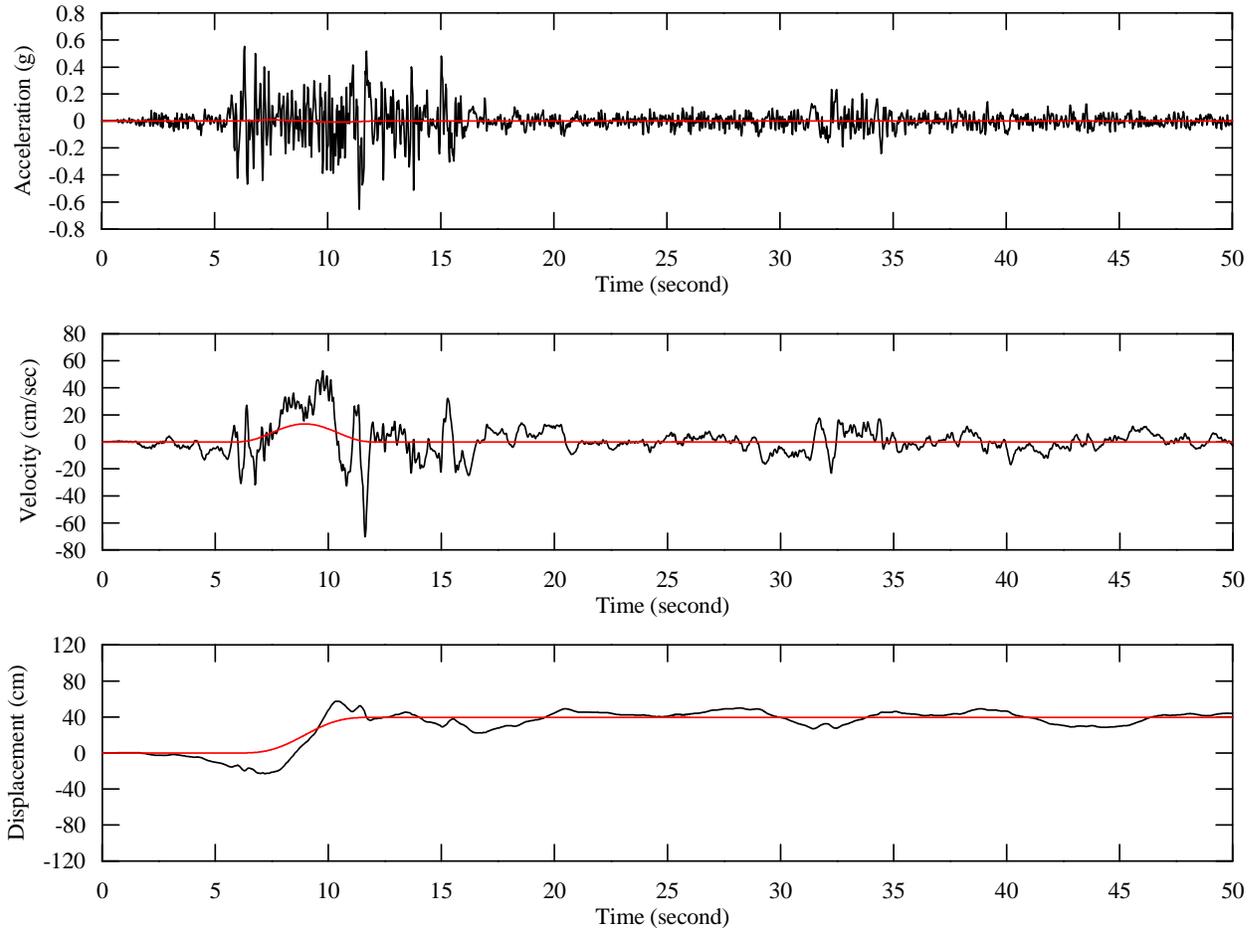


Figure 215: Fault parallel time histories including fling at ground surface, 1990 Manjil Earthquake

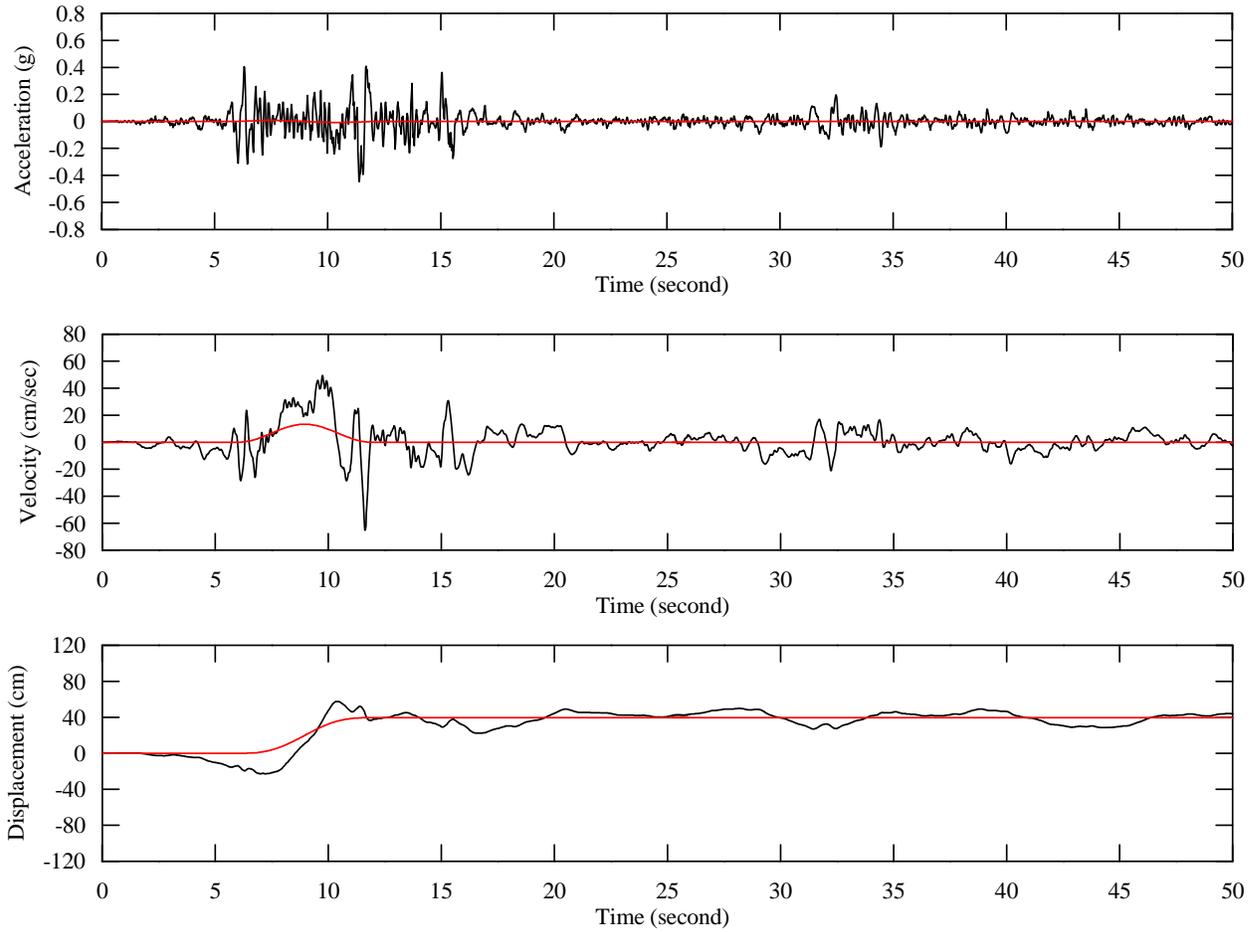


Figure 216: Fault parallel time histories including fling at the bottom of retaining wall, 1990 Manjil Earthquake

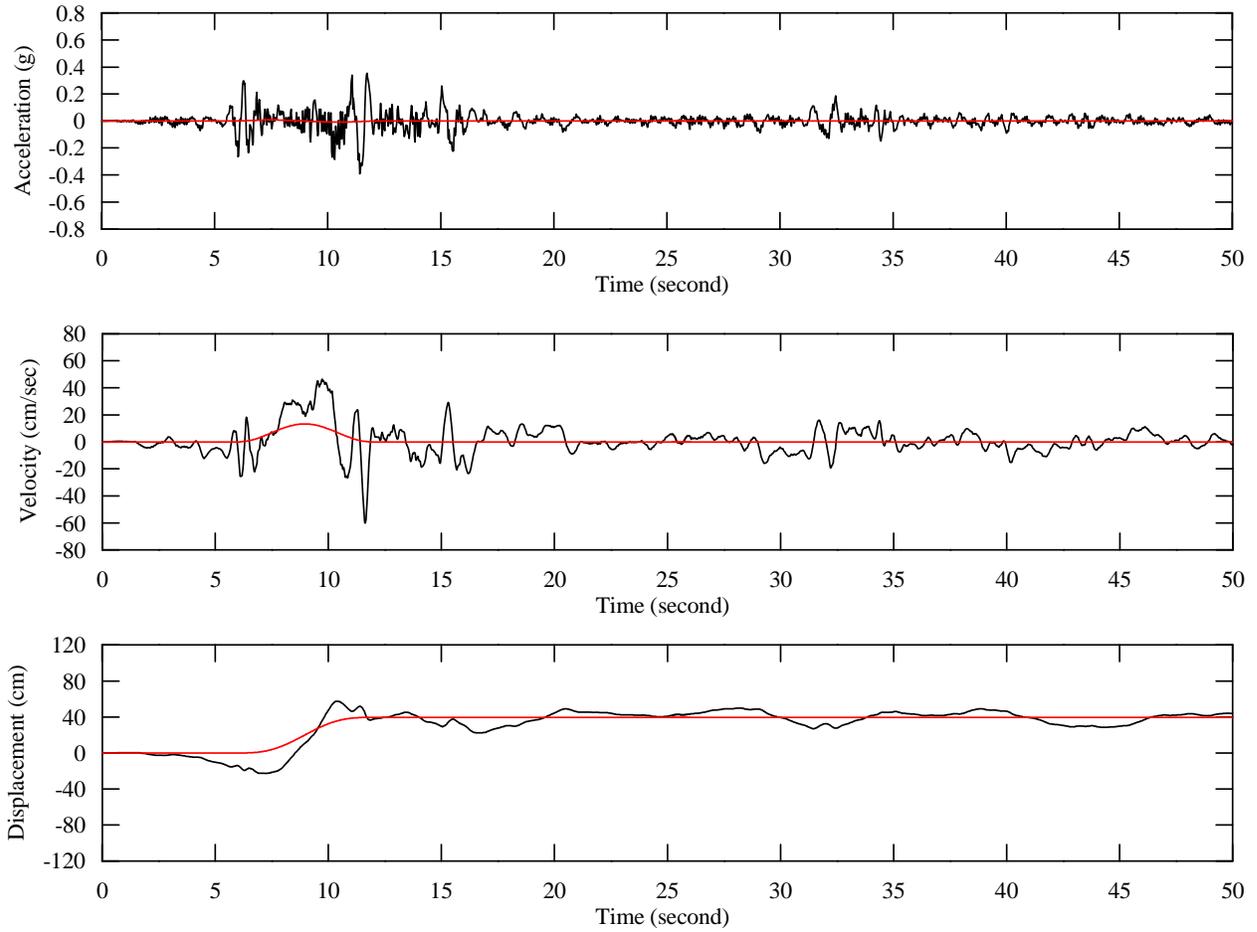


Figure 217: Fault parallel time histories including fling at 20ft below bottom of retaining wall, 1990 Manjil Earthquake

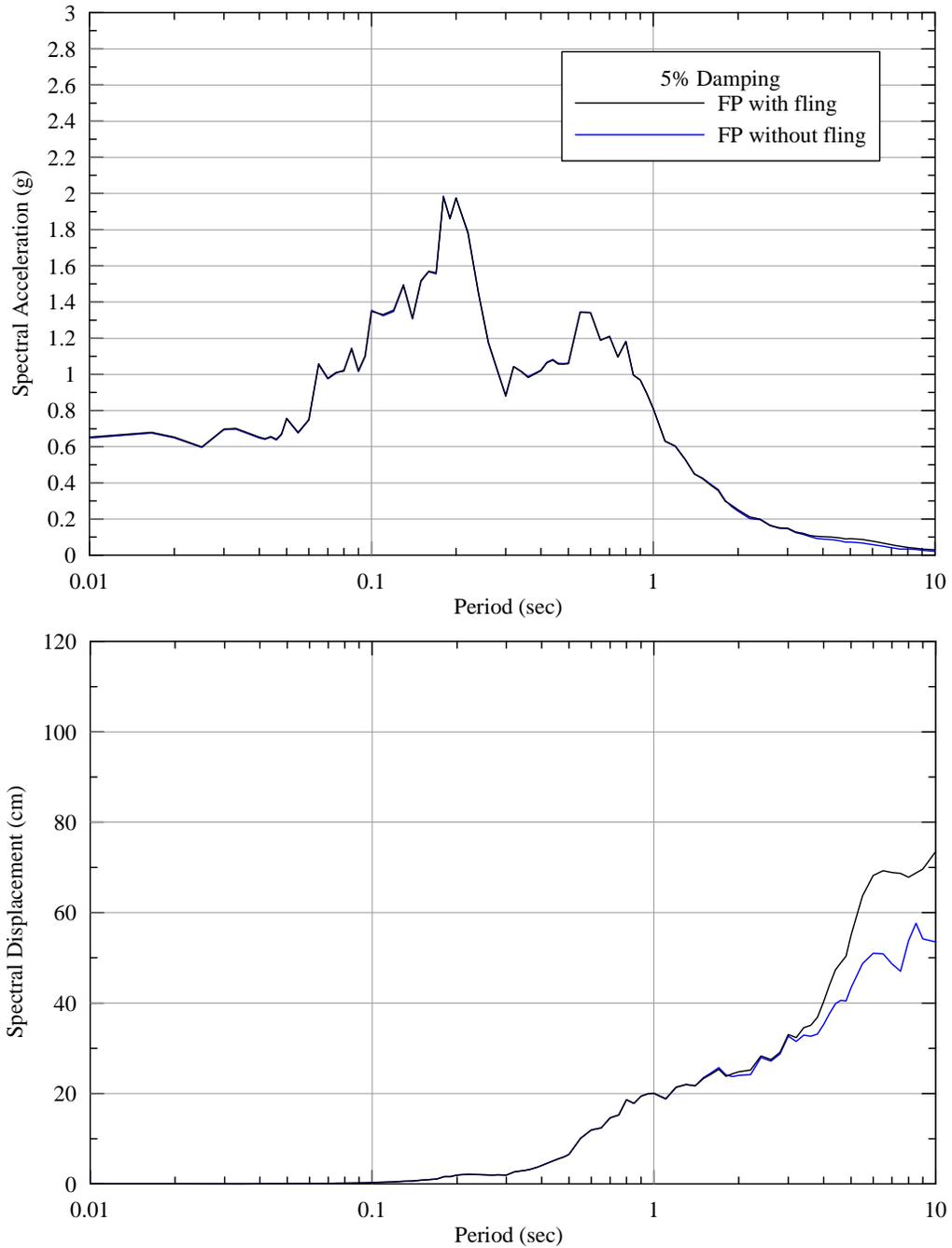


Figure 218: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1990 Manjil Earthquake

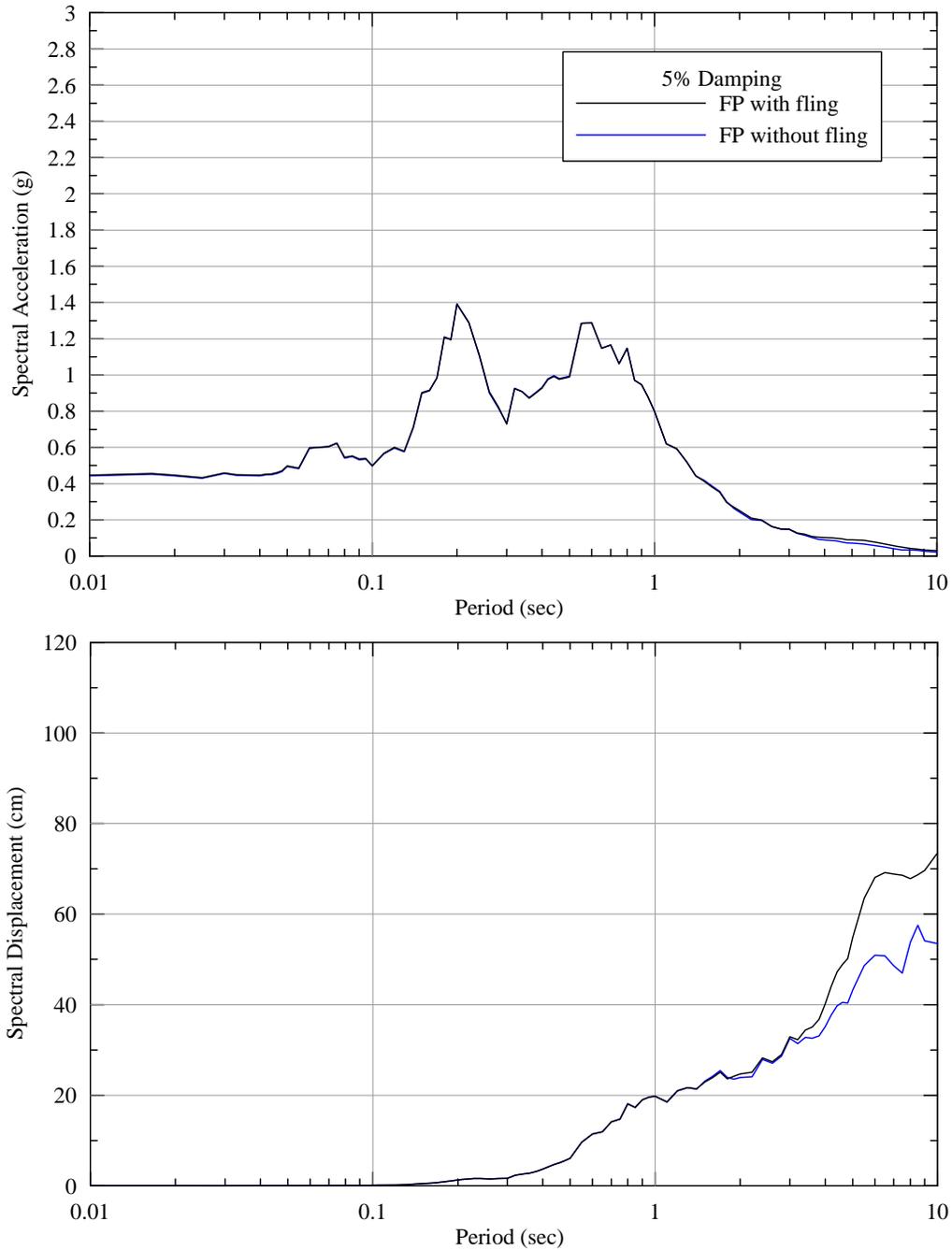


Figure 219: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at the bottom of retaining wall, 1990 Manjil Earthquake

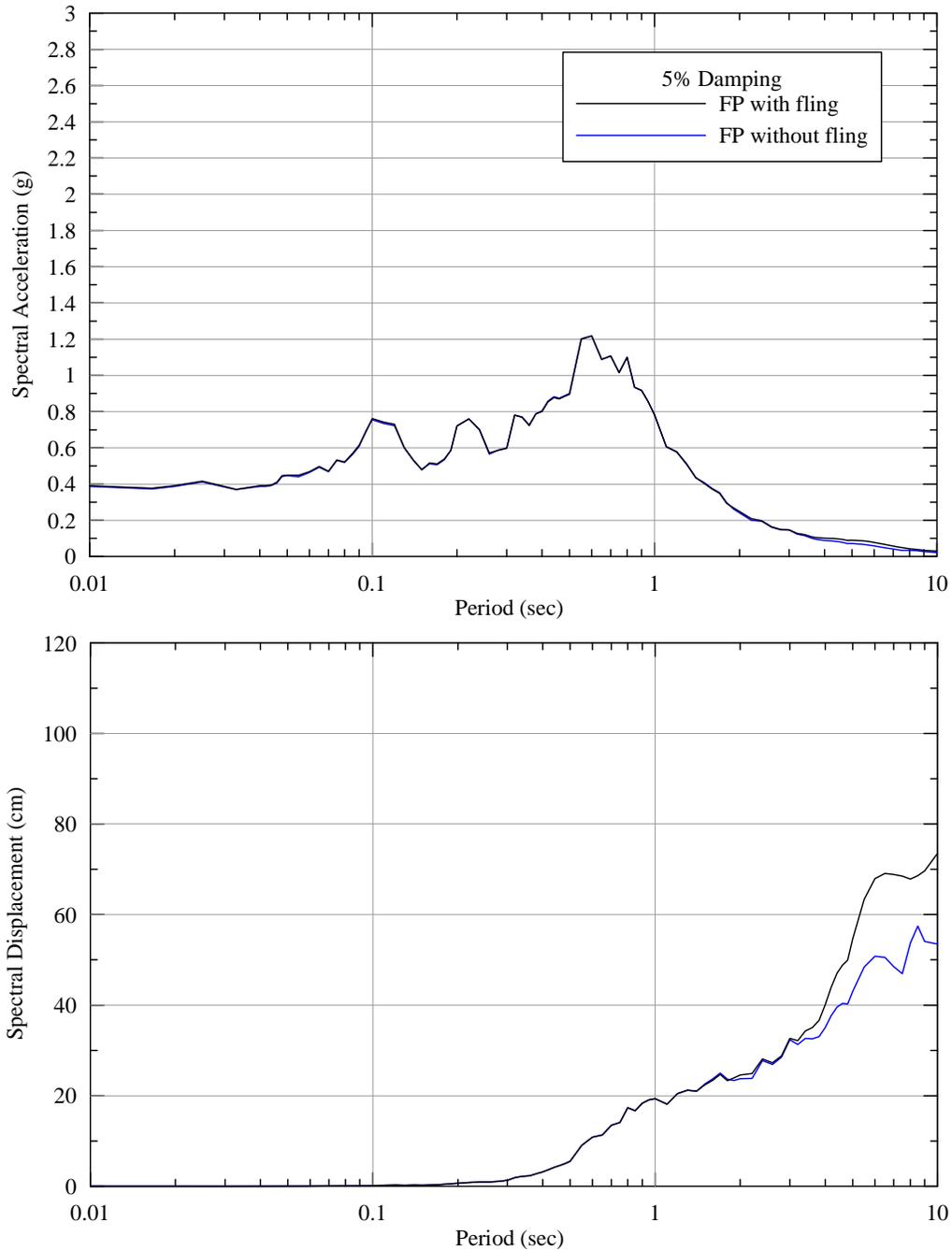


Figure 220: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at 20ft below bottom of retaining wall, 1990 Manjil Earthquake

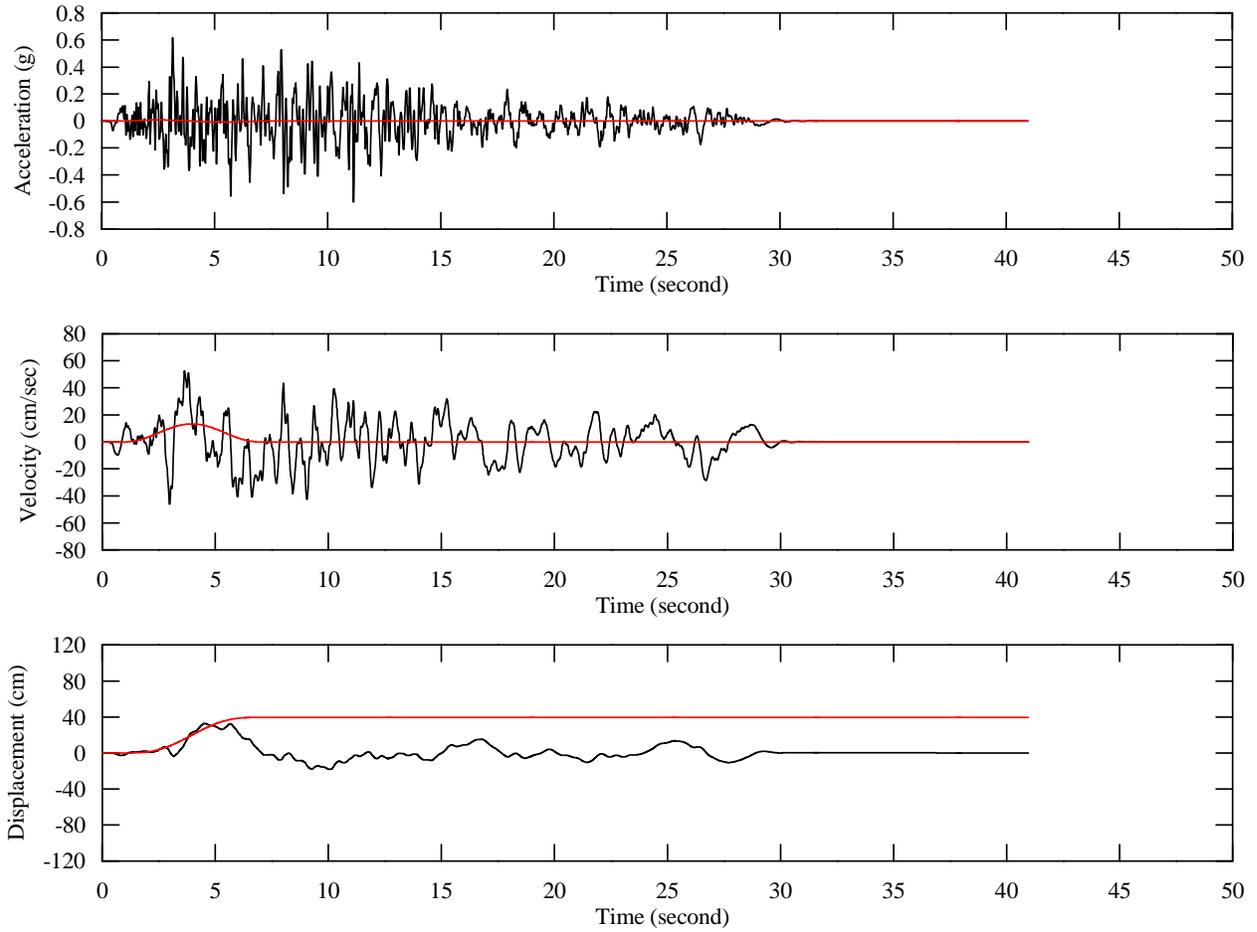


Figure 221: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1999 Kocaeli Earthquake

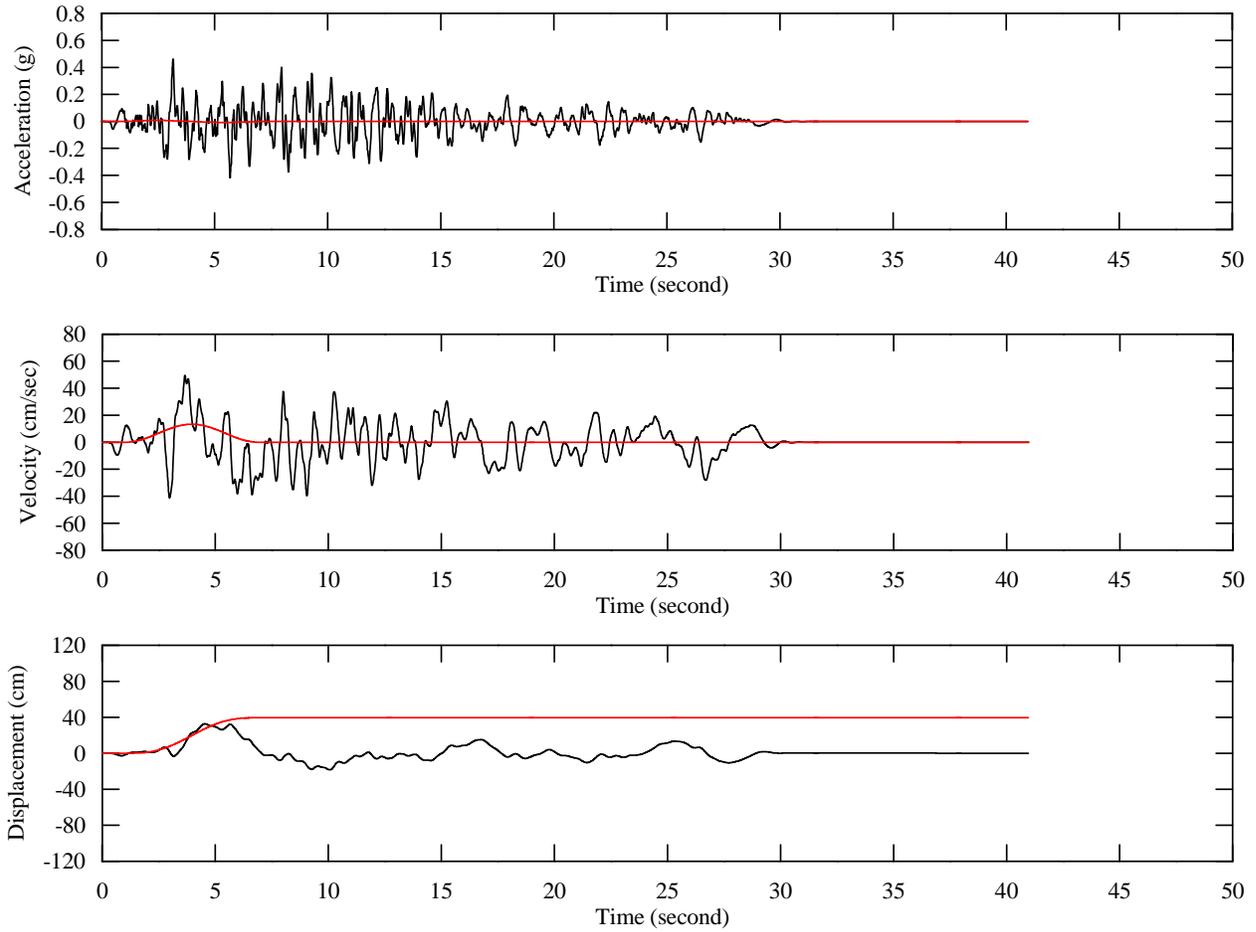


Figure 222: Fault parallel time histories at the bottom of retaining wall from site response analysis and fling time histories, 1999 Kocaeli Earthquake

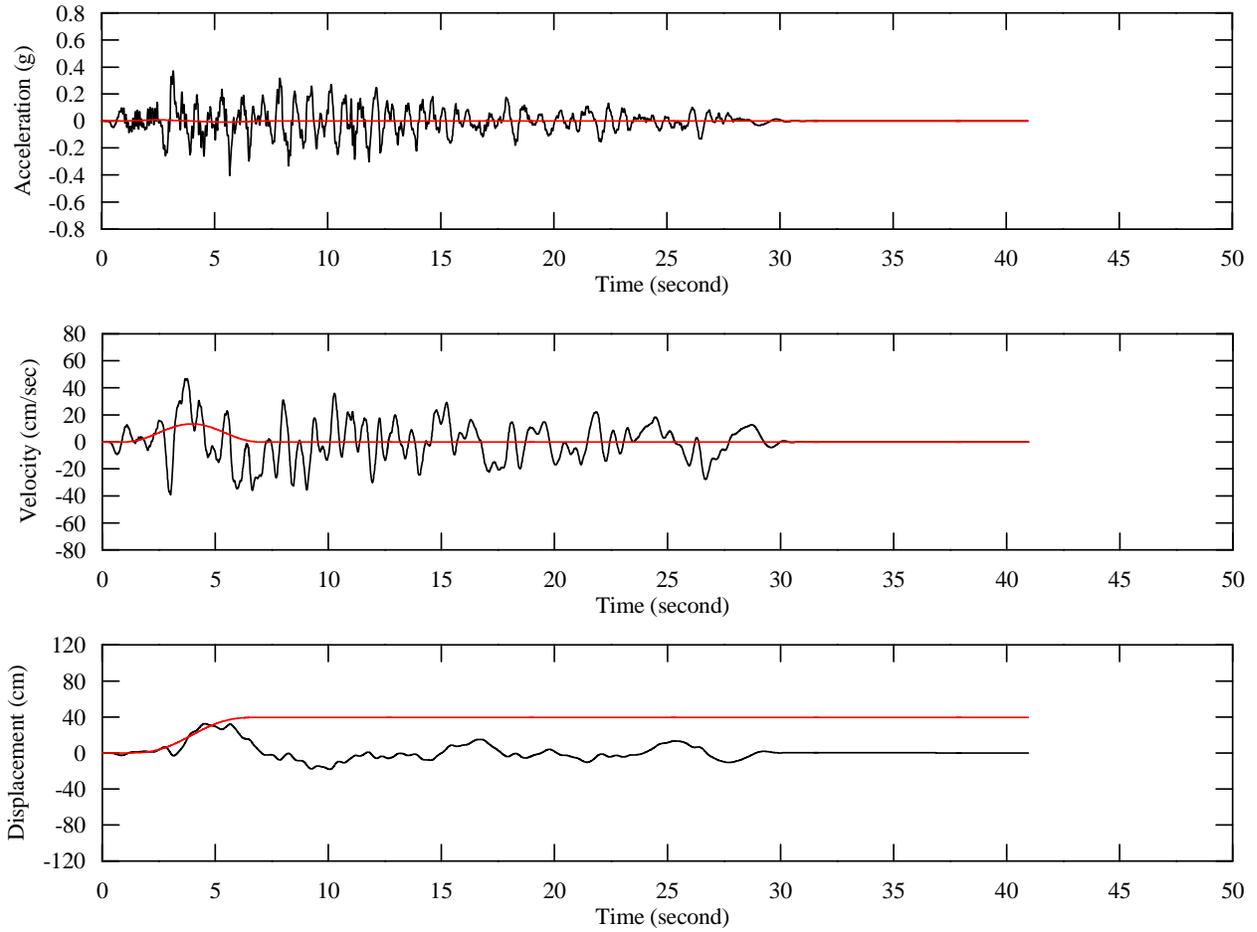


Figure 223: Fault parallel time histories at 20ft below bottom of retaining wall from site response analysis and fling time histories, 1999 Kocaeli Earthquake

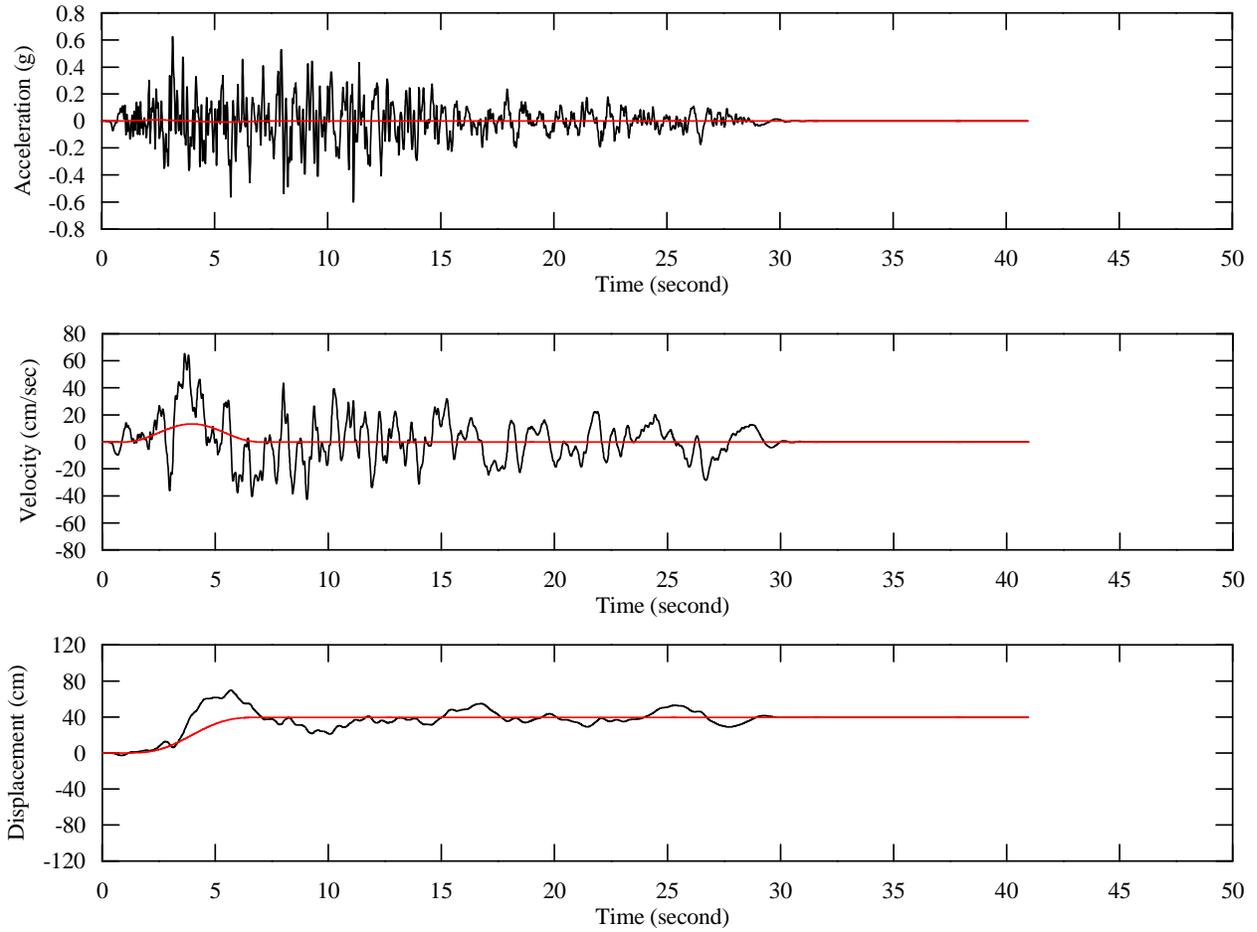


Figure 224: Fault parallel time histories including fling at ground surface, 1999 Kocaeli Earthquake

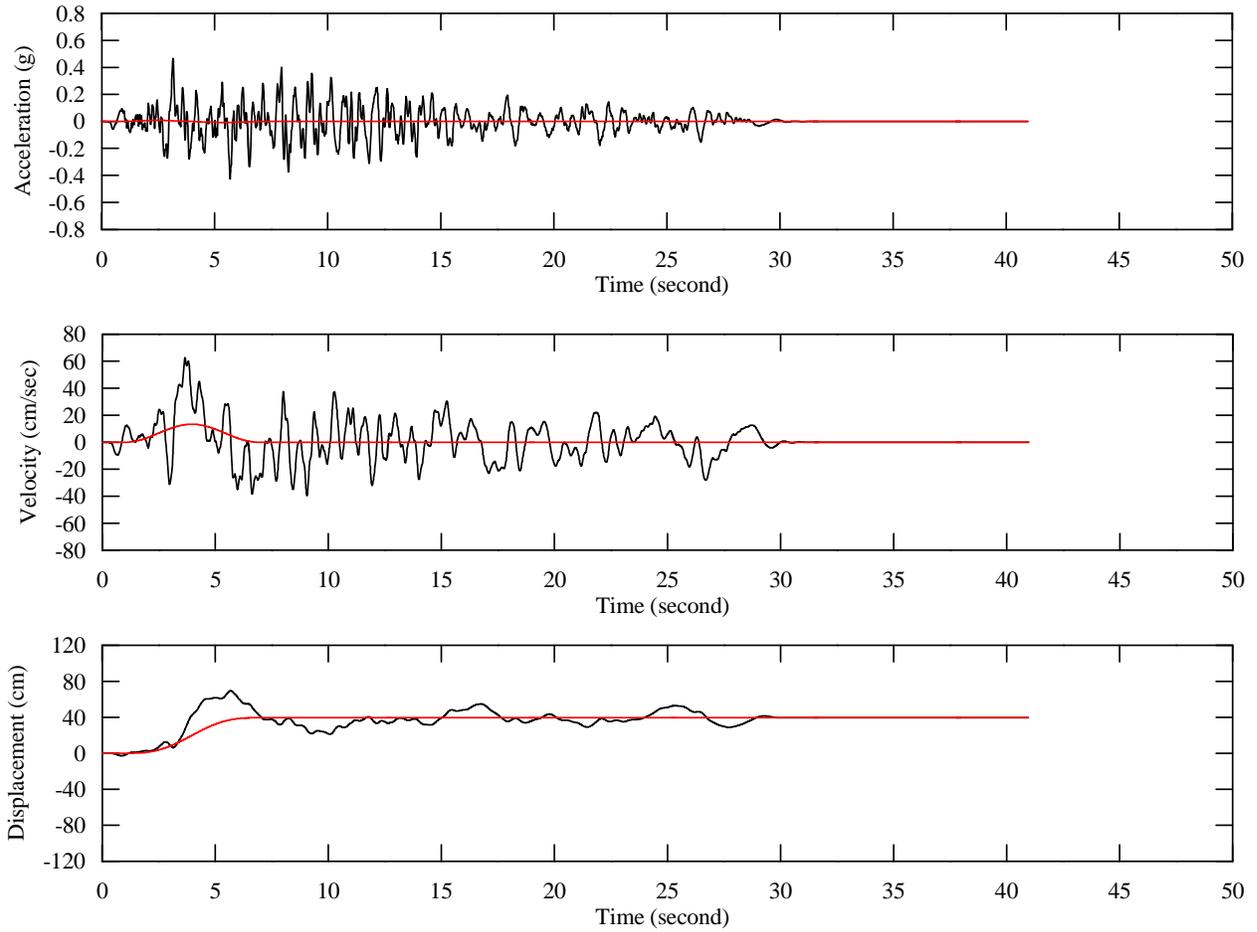


Figure 225: Fault parallel time histories including fling at the bottom of retaining wall, 1999 Kocaeli Earthquake

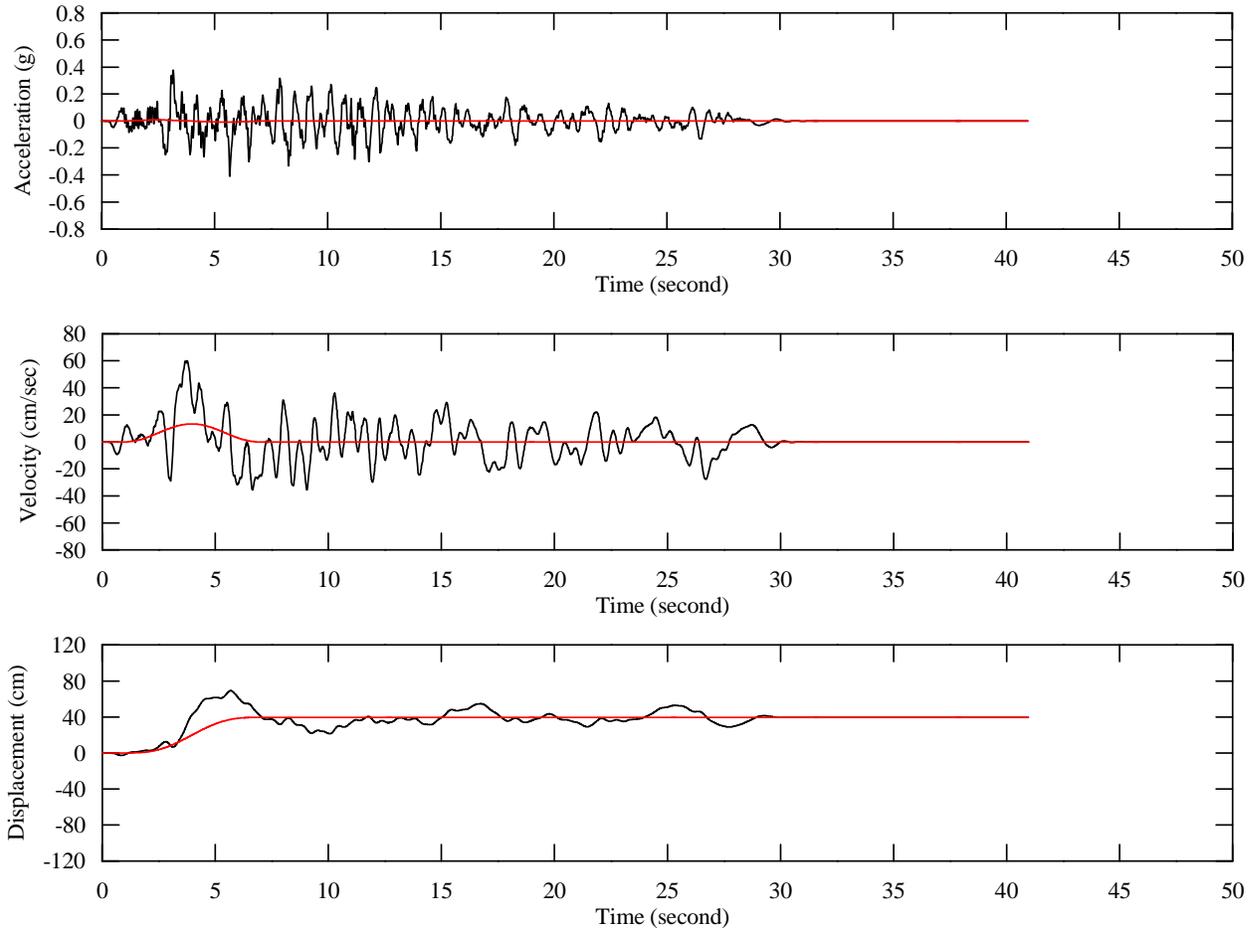


Figure 226: Fault parallel time histories including fling at 20ft below bottom of retaining wall, 1999 Kocaeli Earthquake

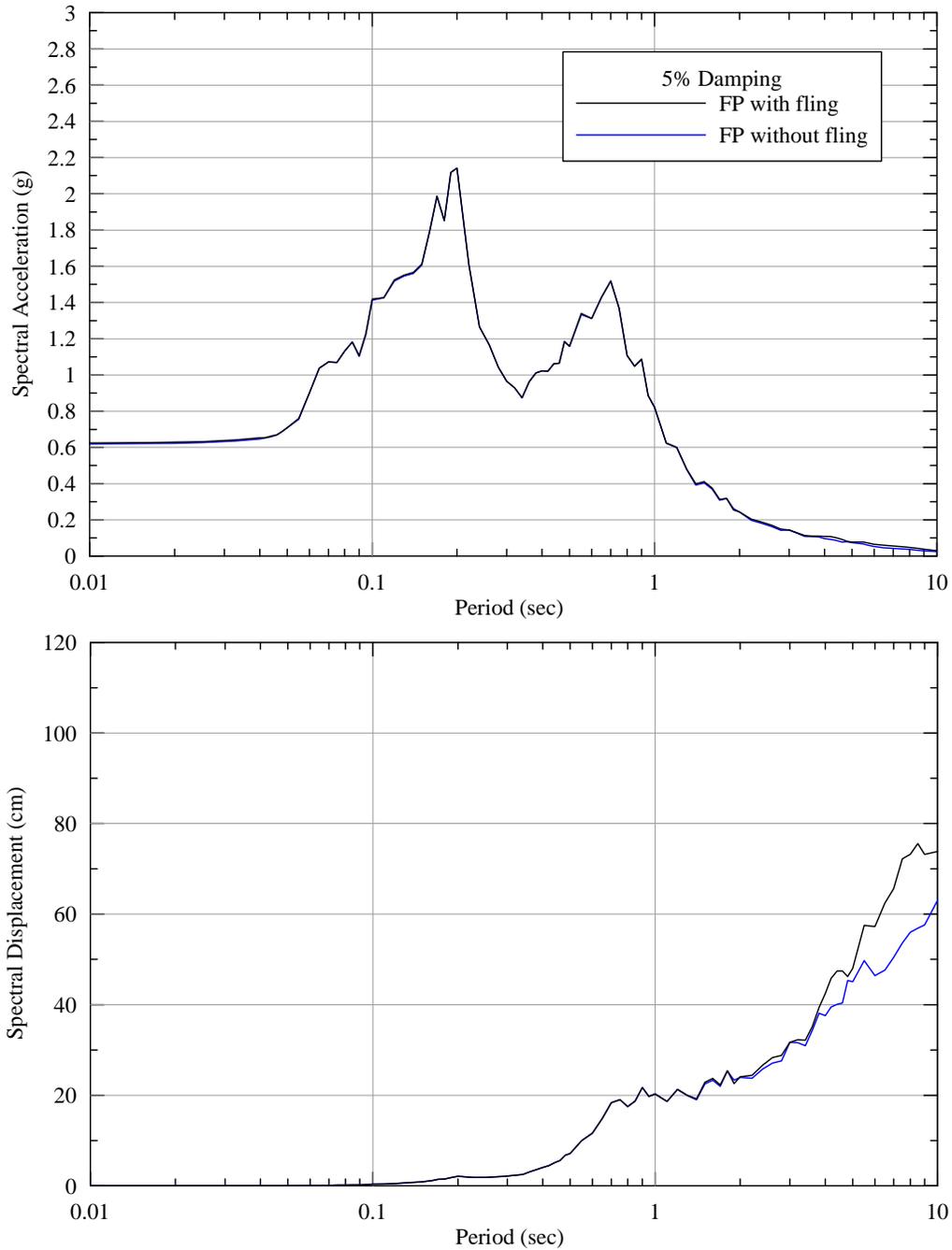


Figure 227: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1999 Kocaeli Earthquake

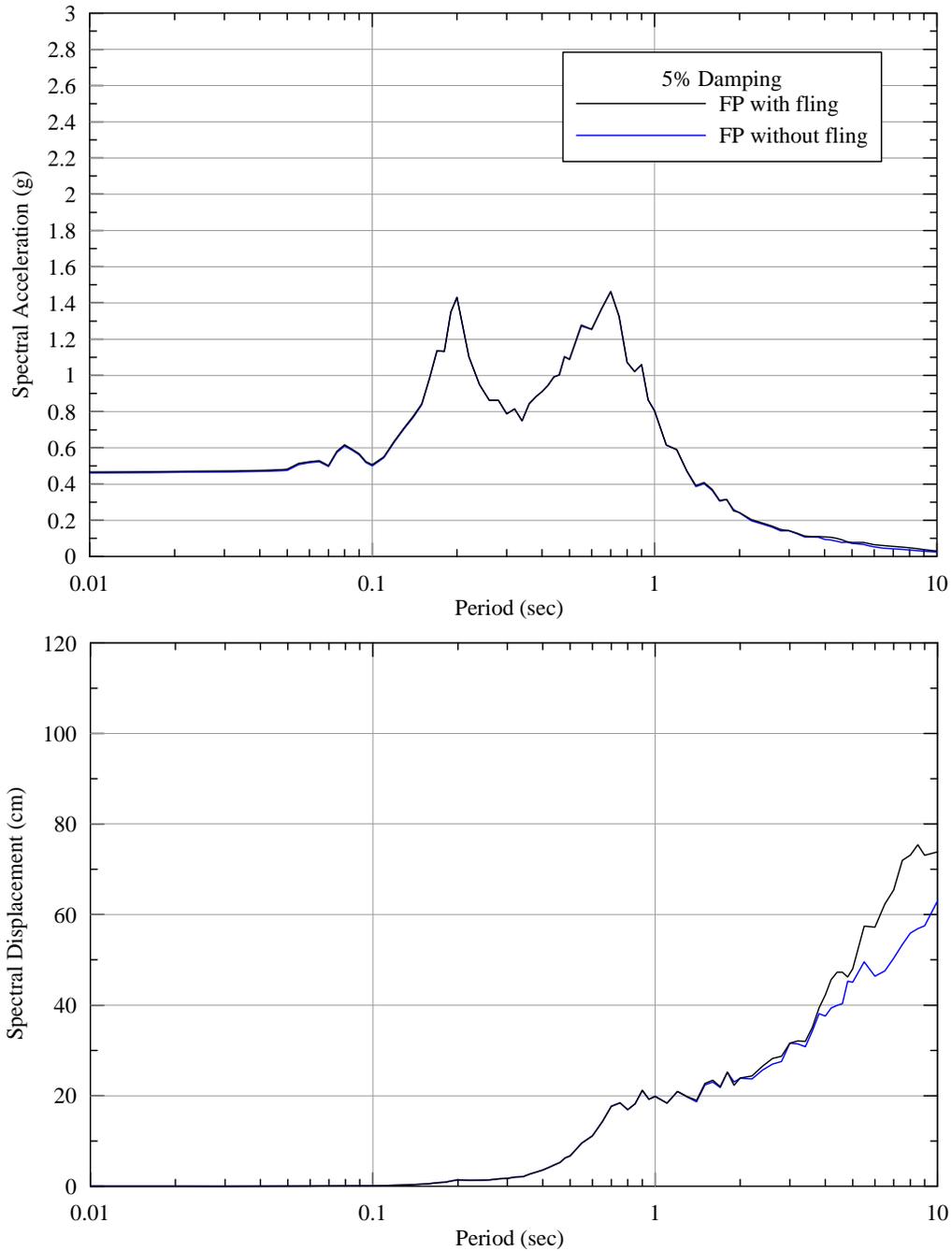


Figure 228: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at the bottom of retaining wall, 1999 Kocaeli Earthquake

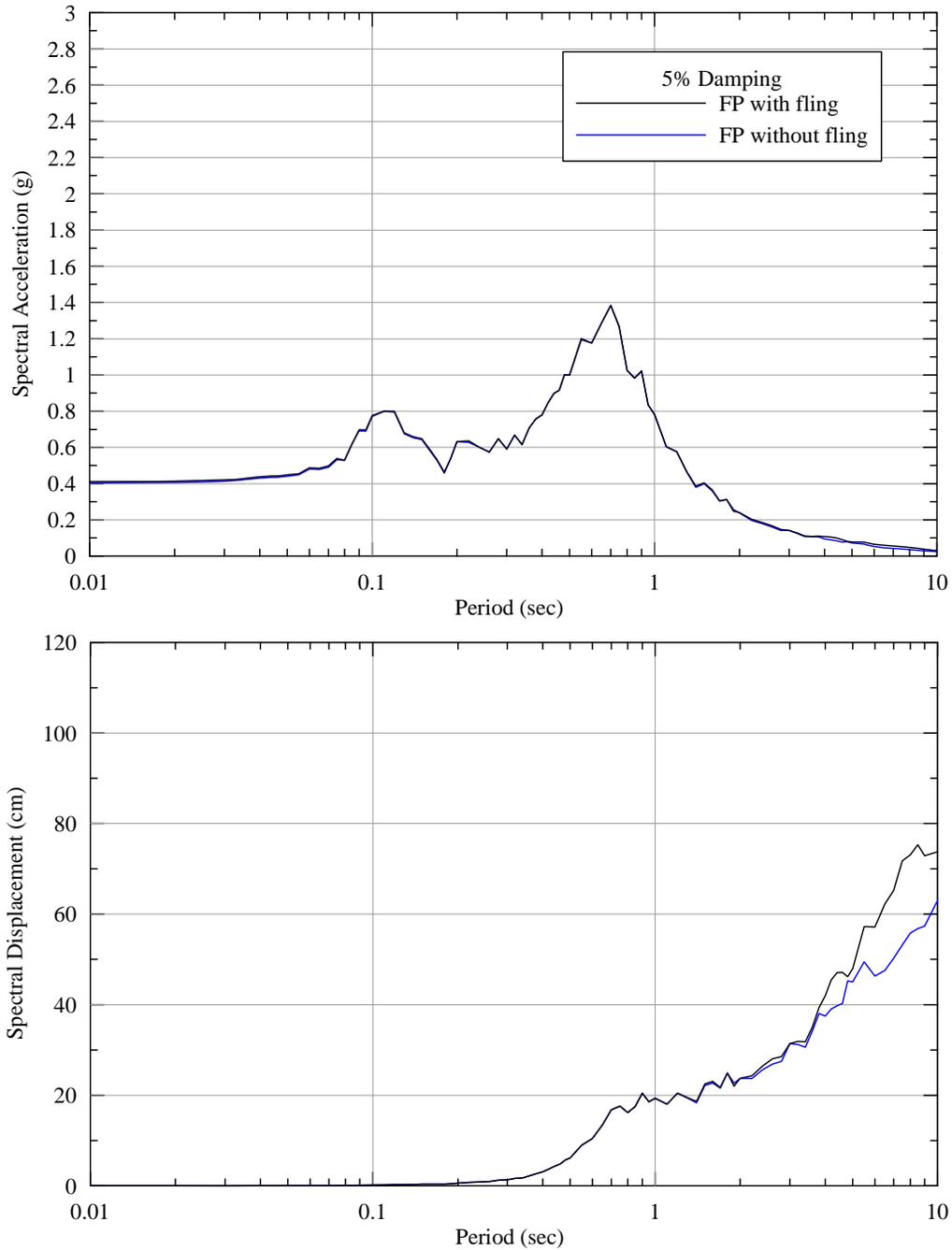


Figure 229: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at 20ft below bottom of retaining wall, 1999 Kocaeli Earthquake

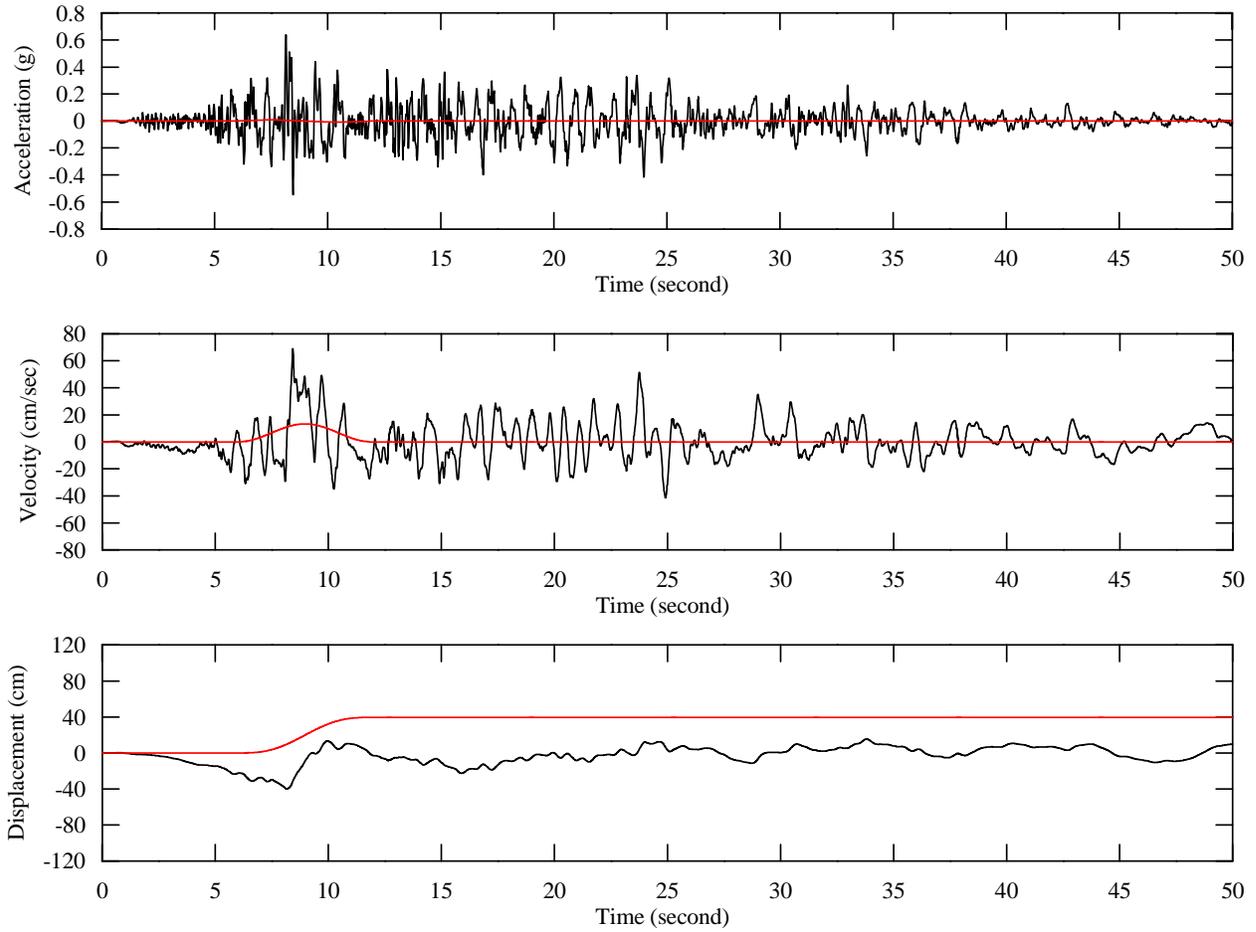


Figure 230: Fault parallel time histories at ground surface from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

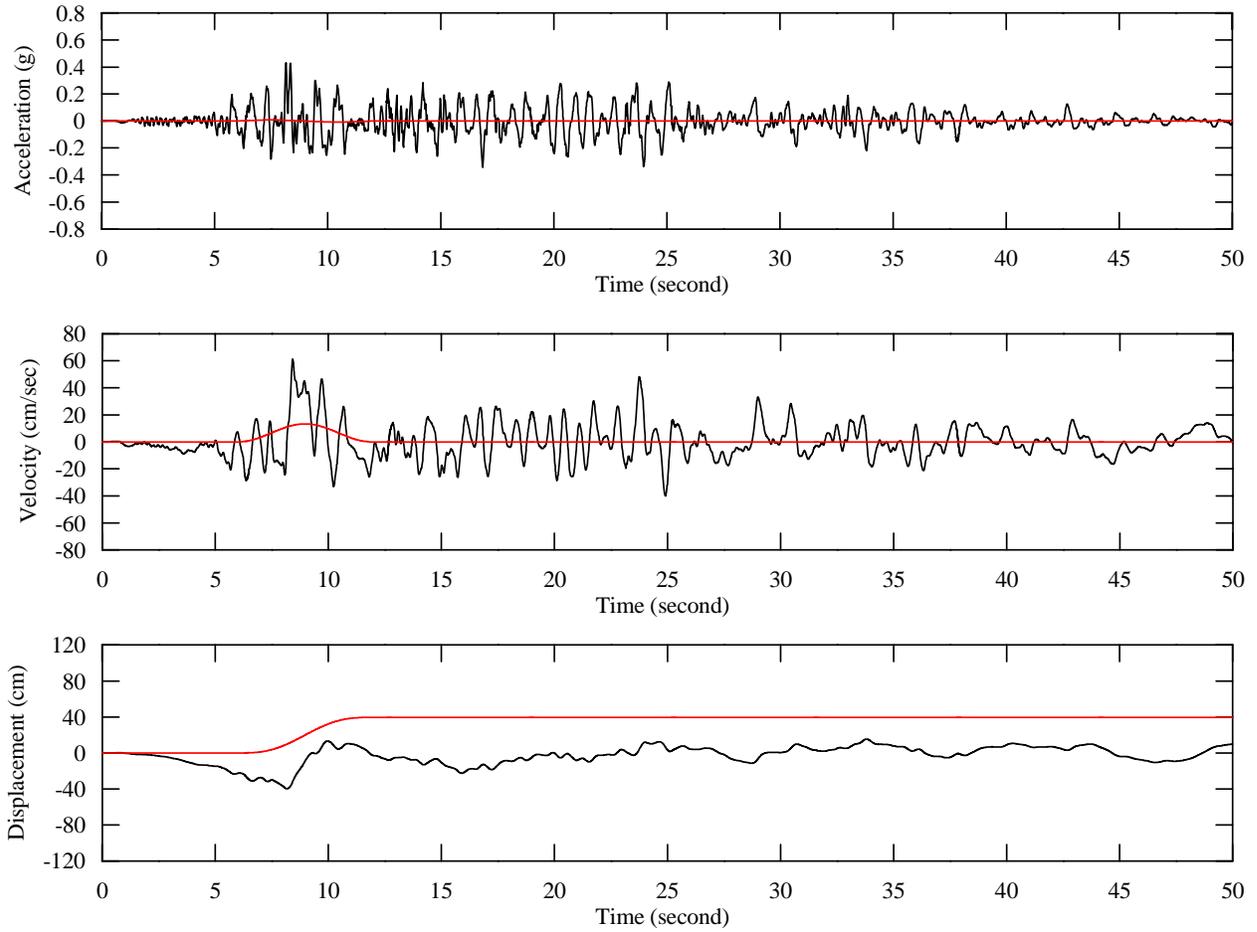


Figure 231: Fault parallel time histories at the bottom of retaining wall from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

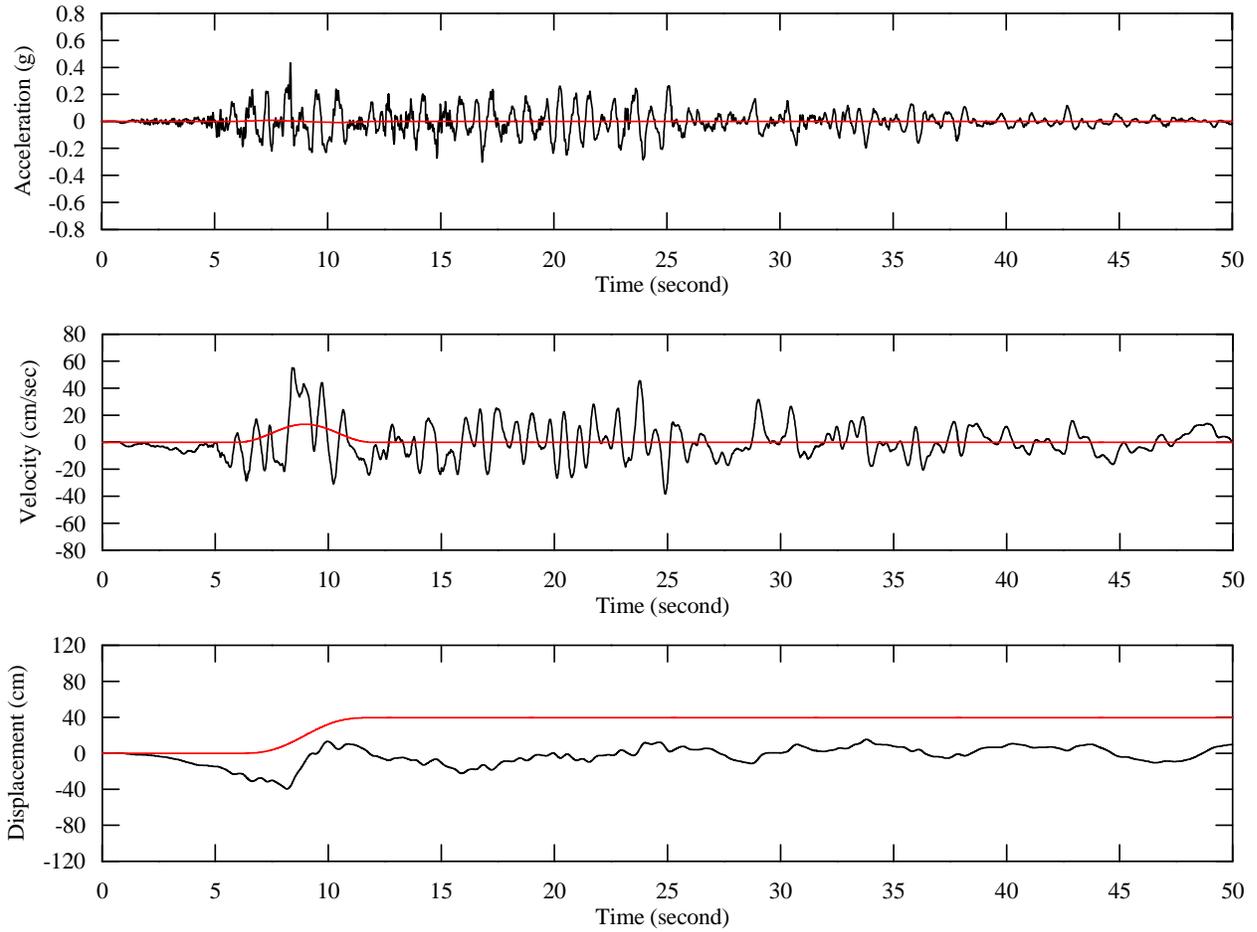


Figure 232: Fault parallel time histories at 20ft below bottom of retaining wall from site response analysis and fling time histories, 1999 Chi-Chi Earthquake

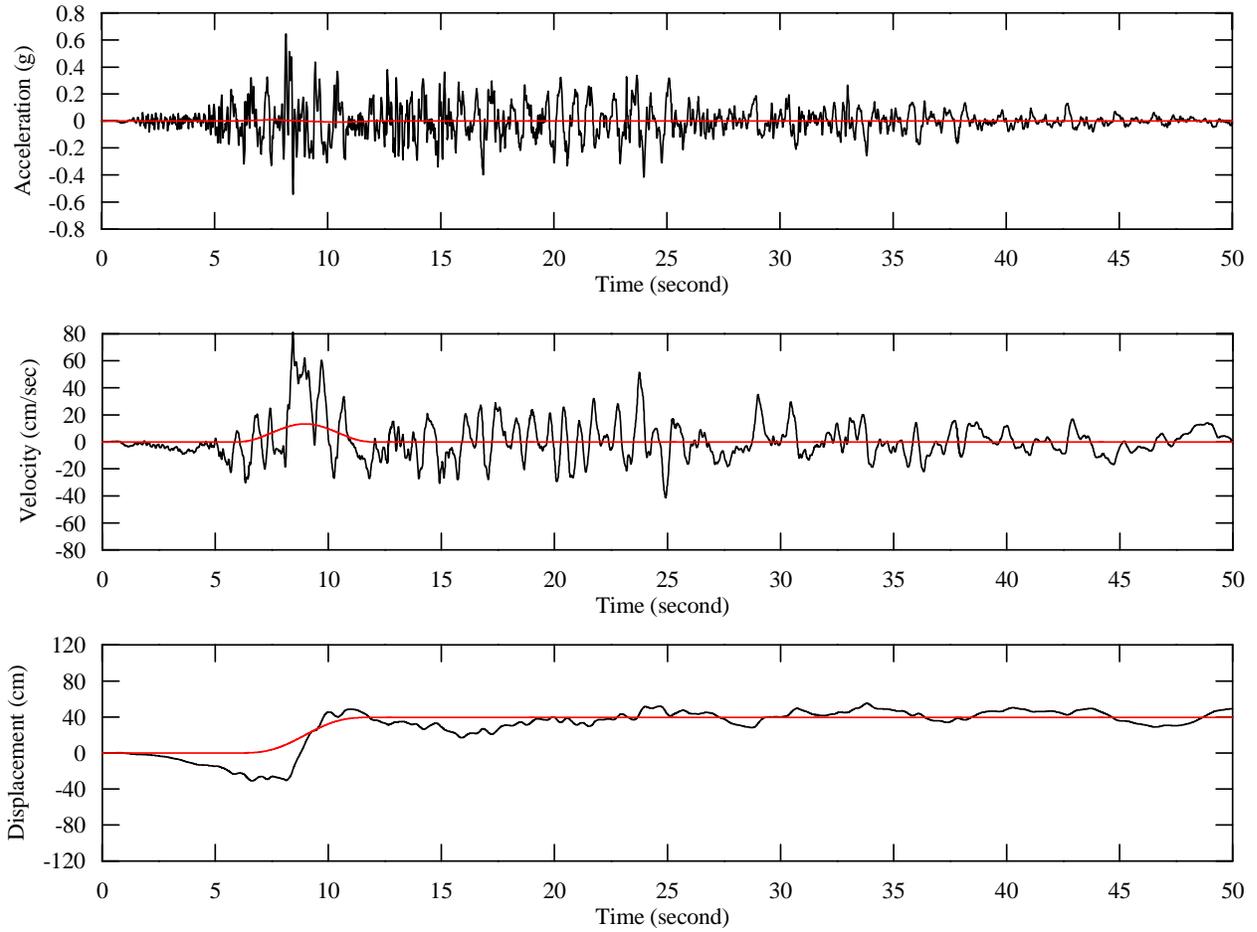


Figure 233: Fault parallel time histories including fling at ground surface, 1999 Chi-Chi Earthquake

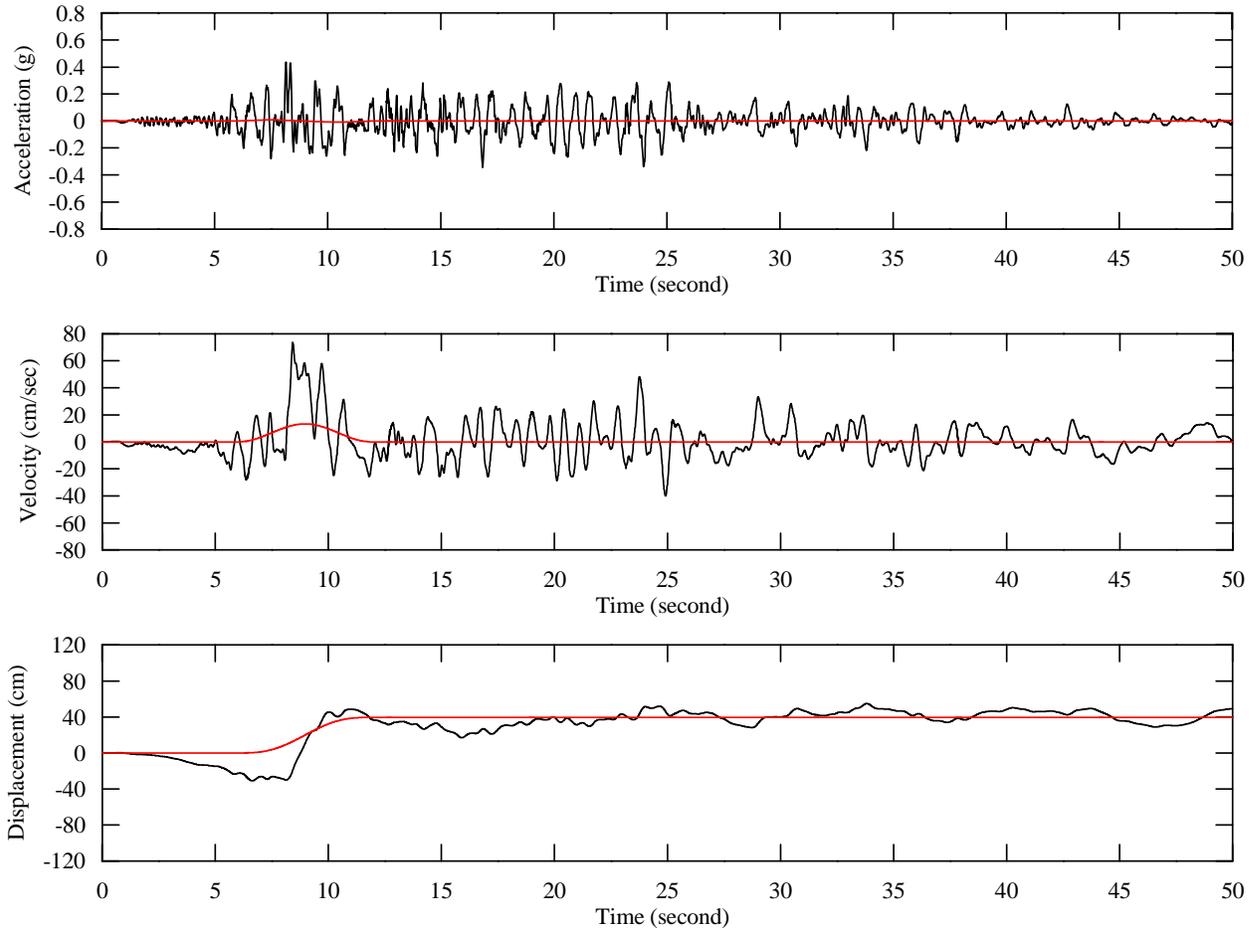


Figure 234: Fault parallel time histories including fling at the bottom of retaining wall, 1999 Chi-Chi Earthquake

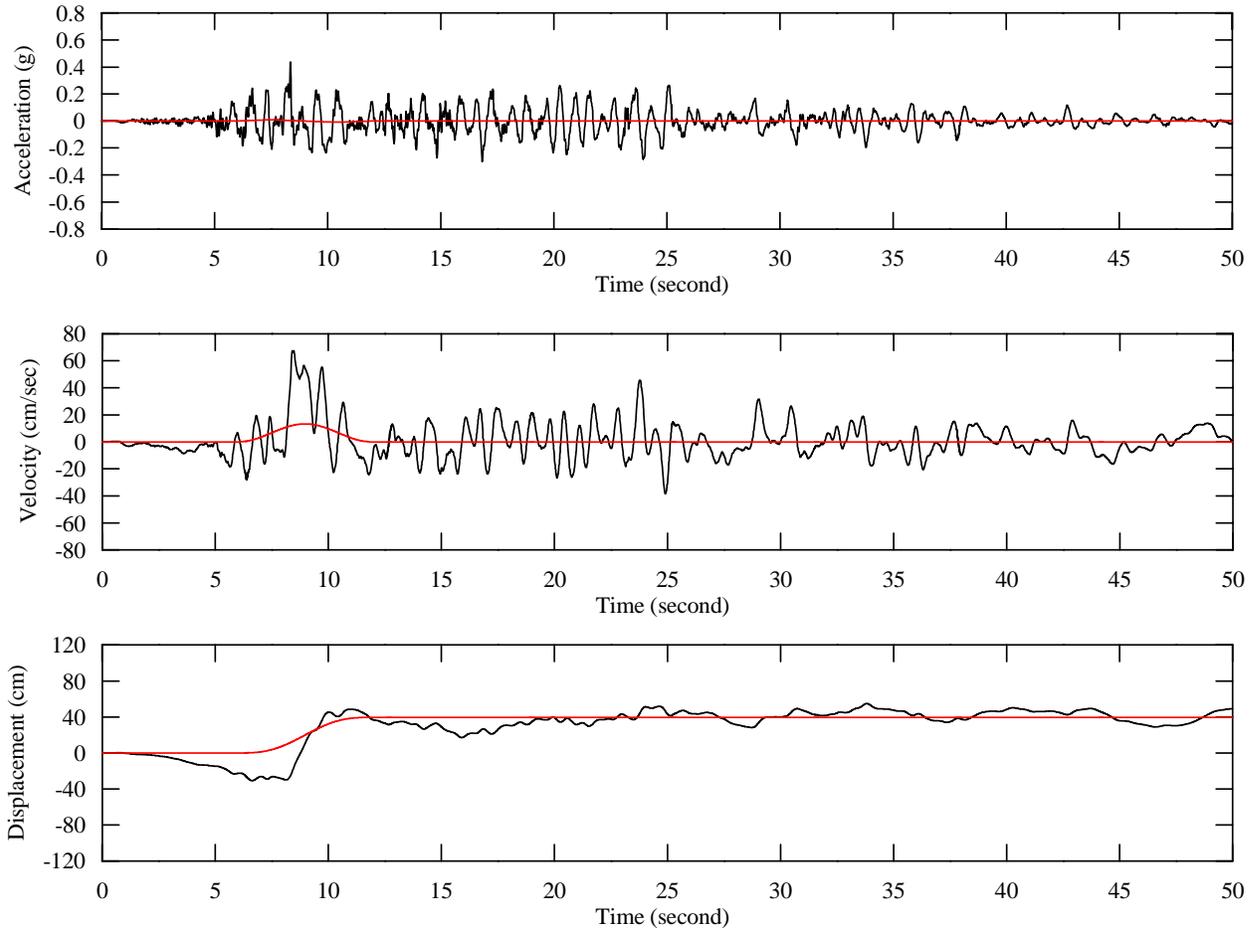


Figure 235: Fault parallel time histories including fling at 20ft below bottom of retaining wall, 1999 Chi-Chi Earthquake

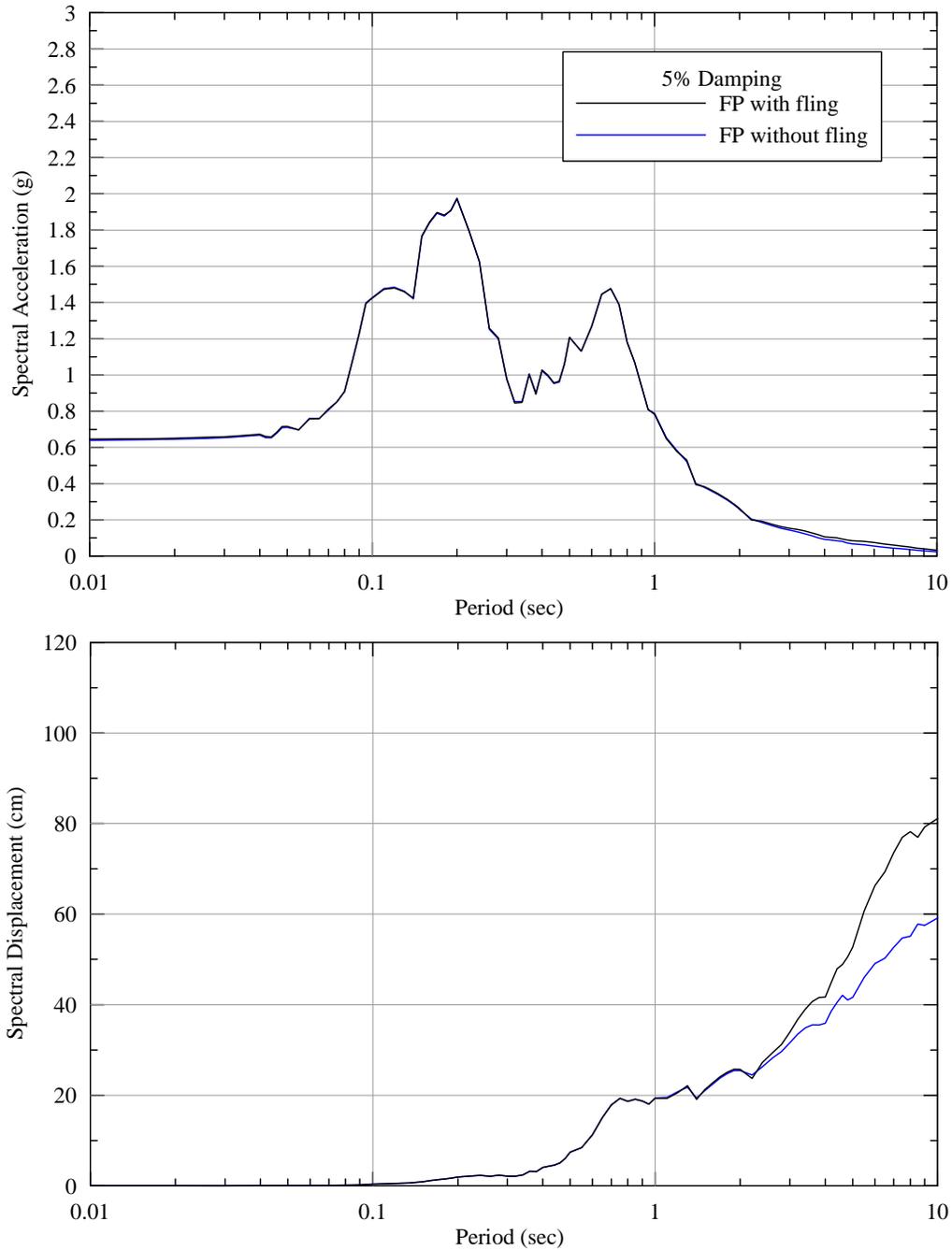


Figure 236: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at ground surface, 1999 Chi-Chi Earthquake

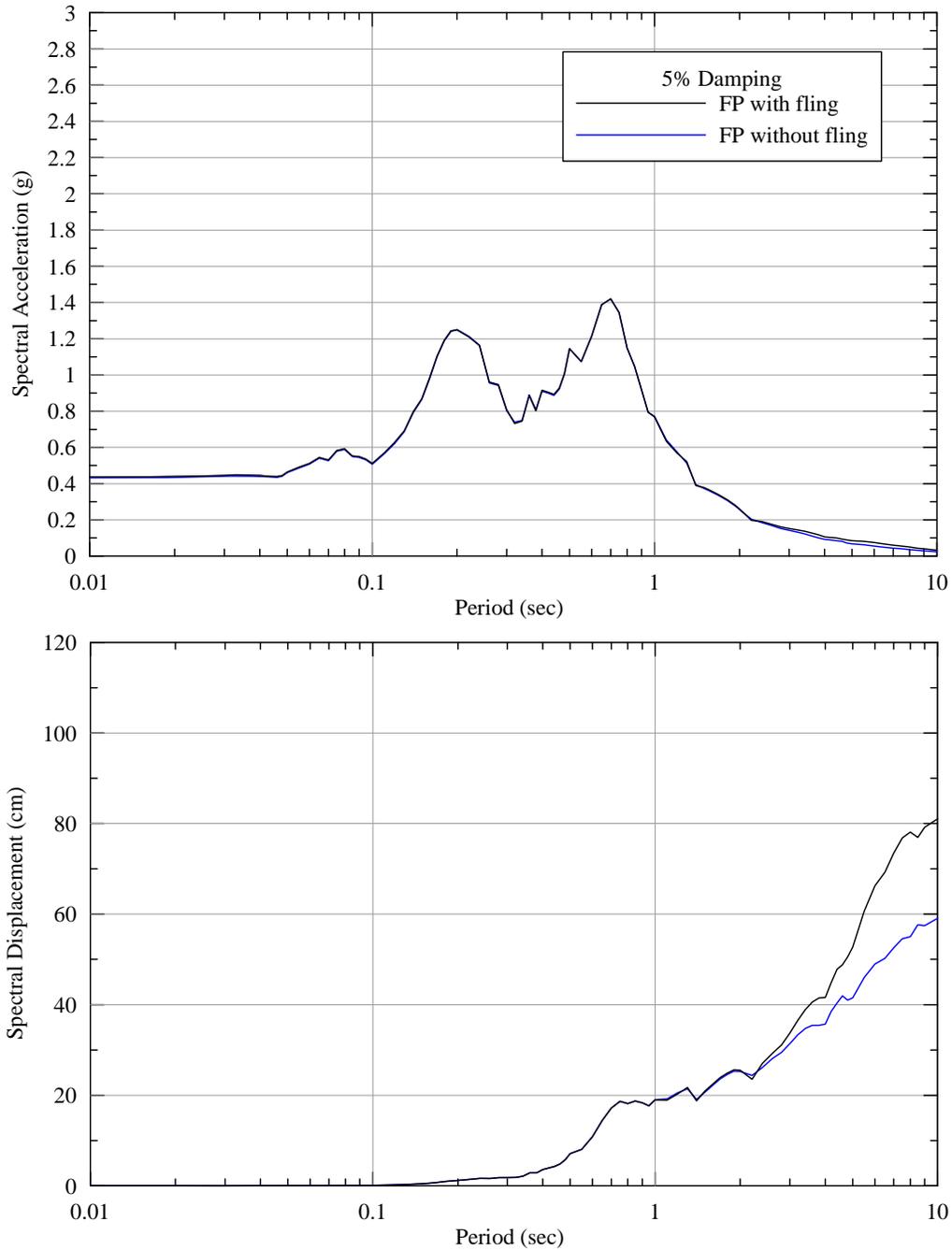


Figure 237: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at the bottom of retaining wall, 1999 Chi- Chi Earthquake

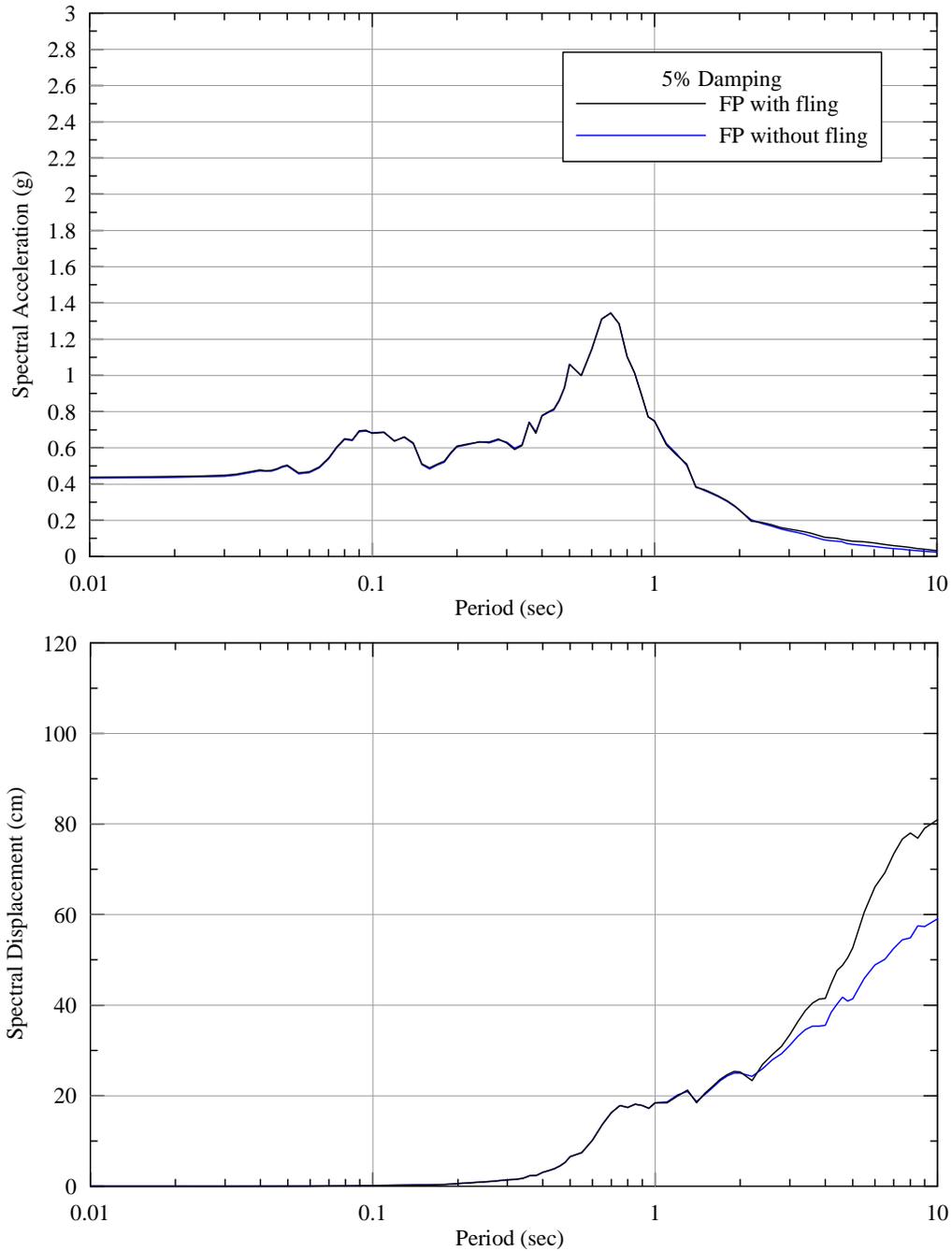


Figure 238: Comparison of acceleration and displacement response spectra between the original and modified (with fling) time histories at 20ft below bottom of retaining wall, 1999 Chi-Chi Earthquake