July 25, 2003, file: `c:\fling_step\fling_step.tex`

"Fling-Step" vs Filtering: Effects on Response Spectra and Peak Motions

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Introduction

This is a brief note comparing response spectra for the north-south component of the TCU068 recording of the 1999 Chi-Chi earthquake processed using a correction for the "fling-step" and using low-cut filtering. I've been meaning to comment on what I understand to be the correction for "fling-step", one of the tasks of Working Group 1 of the PEER NGA project. Because I will not be here for the WG1 discussions, I thought I should launch a pre-emptive strike (my missile might be a dud). This is my only shot at what is a somewhat moving target (I've seen nothing written down and am responding to oral comments made by Norm Abrahamson at various PEER NGA meetings.)

The displacement derived from the TCU068 record has an overshoot before settling down to a large residual displacement, and for this reason it is a prime example of a record with a "fling-step". I may be missing something, but I do not understand from wave propagation how to separate the far-, intermediate, and near-field terms that in the aggregate determine the ground motion. The separation between these terms is somewhat artificial, depending on distance and the frequency of motion. The residual displacement is a consequence of wave propagation from a finite dislocation; its form is entirely predicted by the elastodynamic equations — the residual displacement is not produced by some other physical process. One reason given for removing "fling-step" is that it might contaminate response spectra and peak motions when included with data that do not show obvious residual displacements in regression analyses to derive equations for predicting strong ground motions. My conclusion is that if the effects of residual displacements are to be removed (and I am not convinced that they should be removed), filtering works as well as the somewhat arbitrary procedure of removing the "fling-step" by subtracting a single cycle of a sine wave from the acceleration time series.

A Procedure for Removing "Fling-Step"

I remove a single cycle of a sine wave from the acceleration trace (I think this is the procedure advocated by Norm. Abrahamson). The pulse is determined by three parameters: the start and stop times T_1 and T_2 and the amplitude A. These parameters are chosen by inspecting the displacement trace of an acceleration time series corrected for any baseline offsets so as to give a relatively flat residual displacement D. The pulse parameters are related through the following equations:

$$a(t) = A \sin \frac{2\pi(t - T_1)}{T} \tag{1}$$

$$v(t) = A\frac{T}{2\pi}[1 - \cos \frac{2\pi(t - T_1)}{T}] \tag{2}$$

$$d(t) = A\frac{T}{2\pi}[(t - T_1) - \frac{T}{2\pi} \sin \frac{2\pi(t - T_1)}{T}] \tag{3}$$

where $T = T_2 - T_1$ and $T_1 \leq t \leq T_2$. From the last equation,

$$D = A\frac{T^2}{2\pi} \tag{4}$$

from which

$$A = D\frac{2\pi}{T^2} \tag{5}$$

Choosing D and T_1 seems straightforward, but I am not sure what criteria to use for choosing T_2. In the examples to follow I use a series of values spanning what seems to be a reasonable range, as determined by inspection of the displacement before removing the residual displacement.

Peak Motions and Response Spectra obtained from Accelerations
Corrected using the "Fling-Step" Removal and Low-Cut Filtering

Applying the processing to the north component of the station TCU068 recording of the Chi-Chi earthquake, corrected using the "v0" correction, gives the velocity and displacement time series shown in Figures 1, 2, and 3. Figure 1 shows the results from correcting the accelerations for the “fling-step” correction, for a series of T_2 values and T_1 fixed at 30 sec. Figures 2 and 3 show the results of causal and acausal low-cut filtering applied to the acceleration traces before integrating to velocity and displacement. The v0-corrected time series was padded with 150 sec of leading and 150 of trailing zeros before the acausal filtering; these pads are not shown in the figure. The peak accelerations, velocities, and displacements are given in Tables 1, 2, and 3. Relative displacement and pseudo-absolute acceleration response spectra are shown in Figures 4 and 5.

Comments

From the figures and tables, I do not see any advantage to removing the “fling-step”. For all methods the peak motions are dependent on the processing parameters, particularly the peak displacements. Here are a few observations:

1. The decrease in velocity is similar for both filtered and ‘fling-step” corrected data.

2. The peak displacement for the “fling-step” corrected time series goes to a minimum and then grows as T_2 is decreased, whereas for the filtered records the peak displacements decrease monotonically. Is the minimum in the peak displacement for the “fling-step” corrected time series a basis for choosing T_2? If so, it seems arbitrary.

3. The SD from filtered and sine-removed accelerations can be quite similar. In fact, for periods less than about 10 sec the response spectra are insensitive to how the residual displacements are removed or even if they ARE removed. (The period below which there is little difference will depend on the spectral content of the records; it will presumably be shorter for smaller earthquakes.) It is only the peak velocities and displacements that are sensitive to the processing, but given that they are sensitive, should we be deriving equations for peak displacement (in particular)?

4. The pga for causally filtered records is surprisingly sensitive to the low-cut filter (see Figures 5 and 6)! I pointed this out in a previous note distributed to participants in the PEER NGA project. My conclusion from that note (and from a paper soon to be published in *Earthquake Engineering and Structural Dynamics* by Sinan Akkar and myself) is that causal filtering should not be used. This is relevant to the PEER NGA project because the PEER dataset has been processed using causal filters.

So on balance, why use the “fling-step” corrections if the concern is that the residual displacement is contaminating the motion (and I’m not convinced that this should be a concern)? The choice of T_2 in the correction is just as arbitrary as the choice of the low-cut filter corner, and in both cases the response spectra at lower periods is insensitive to the choice (except for the "extreme" cases of $T_2 = 35$ sec and $f_{lc} = 0.08$ Hz).

	f_smc	flter1	flter2	pkmtn
68NT2V0A.SMC		******	******	364.4
68NT100A.SMC		0.010	-2.000	405.4
68NT050A.SMC		0.020	-2.000	440.0
68NT025A.SMC		0.040	-2.000	492.3
68NT012A.SMC		0.080	-2.000	543.5
68PT100A.SMC		0.010	-1.000	364.4
68PT050A.SMC		0.020	-1.000	364.3
68PT025A.SMC		0.040	-1.000	364.3
68PT012A.SMC		0.080	-1.000	372.2
RMVSN01A.SMC		******	******	374.1
RMVSN45A.SMC		******	******	378.5
RMVSN40A.SMC		******	******	359.1
RMVSN35A.SMC		******	******	403.9

Table 1. Acceleration peak values, from headers of smc files. "`68nt2v0`" is the unfiltered file with "v0" baseline correction; "`68nt100, 050, 025, 012`" are the baseline-corrected file after causal filtering at 100, 50, 25, and 12.5 sec, respectively. The "`68pt`" files are similar, except that acausal filtering of a zero-padded record was used. Finally, the "`rmvsn`" files are the result of removing a sine from `68nt2v0a.smc`, with $T_1 = 30$ sec and $T_2 = 50$, 45, 40, and 35 sec (illogically, "`01`" in the file name corresponds to $T_2 = 50$ sec; the other file names give the value of T_2).

f_smc	flter1	flter2	pkmtn
68NT2V0V.SMC	******	******	292.2
68NT100V.SMC	0.010	-2.000	240.1
68NT050V.SMC	0.020	-2.000	256.4
68NT025V.SMC	0.040	-2.000	235.2
68NT012V.SMC	0.080	-2.000	164.5
68PT100V.SMC	0.010	-1.000	278.4
68PT050V.SMC	0.020	-1.000	264.4
68PT025V.SMC	0.040	-1.000	234.2
68PT012V.SMC	0.080	-1.000	170.4
RMVSN01V.SMC	******	******	248.0
RMVSN45V.SMC	******	******	213.9
RMVSN40V.SMC	******	******	192.3
RMVSN35V.SMC	******	******	292.2

Table 2. Velocity peak values, from headers of smc files.

f_smc	flter1	flter2	pkmtn
68NT2V0D.SMC	******	******	867.8
68NT100D.SMC	0.010	-2.000	587.3
68NT050D.SMC	0.020	-2.000	429.7
68NT025D.SMC	0.040	-2.000	355.8
68NT012D.SMC	0.080	-2.000	230.0
68PT100D.SMC	0.010	-1.000	502.1
68PT050D.SMC	0.020	-1.000	446.2
68PT025D.SMC	0.040	-1.000	343.8
68PT012D.SMC	0.080	-1.000	191.0
RMVSN01D.SMC	******	******	649.2
RMVSN45D.SMC	******	******	487.6
RMVSN40D.SMC	******	******	258.7
RMVSN35D.SMC	******	******	551.1

Table 3. Displacement peak values, from headers of smc files.

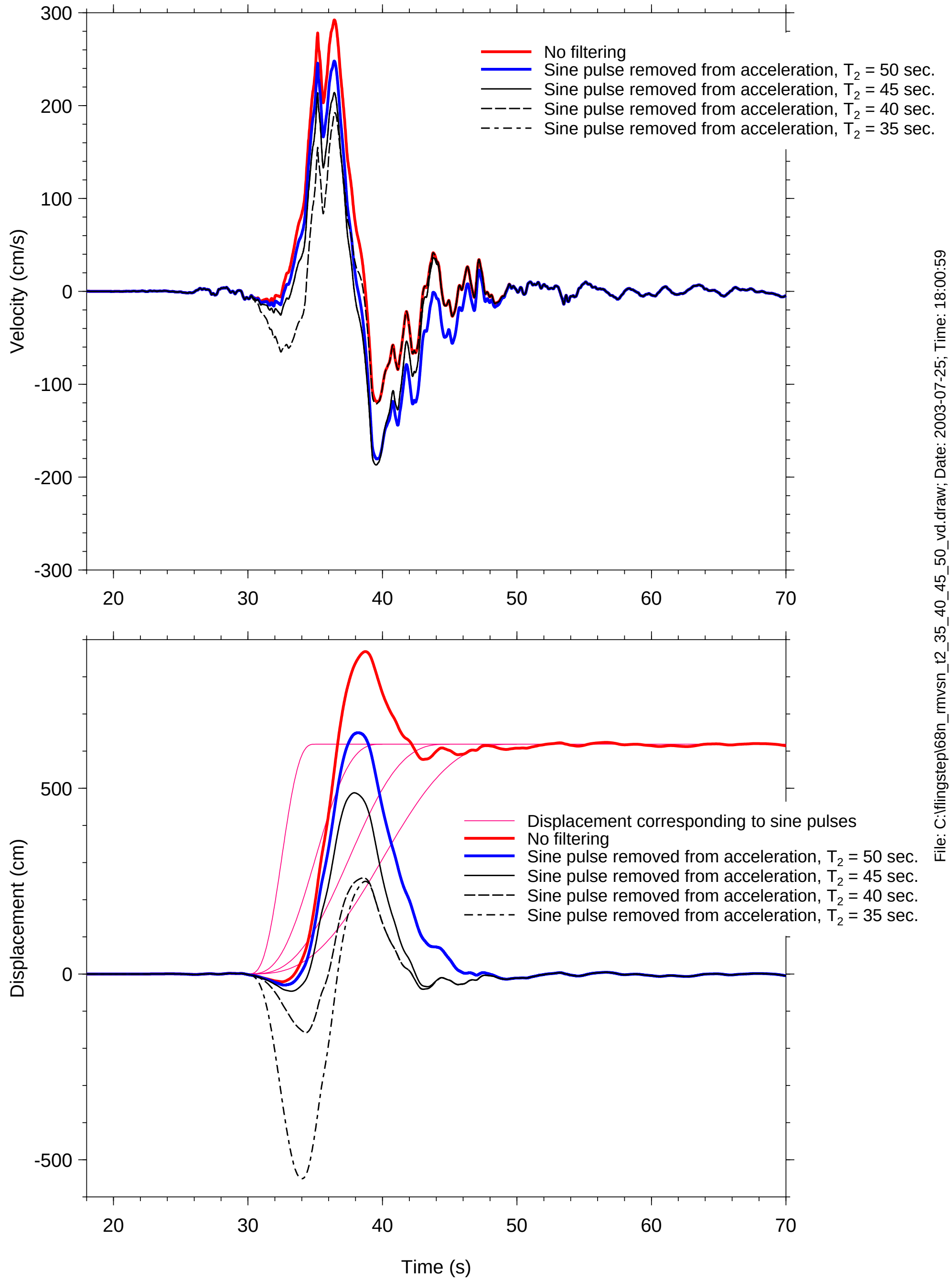

Figure 1. The velocity and displacement time series derived from the TCU068 recording, using the “v0” correction (fit a straightline to the later part of velocity and remove a step in acceleration with amplitude equal to the slope of the fitted line, starting at the time given by the intersection of the fitted line and the zero line in velocity; the result is labeled “No filtering”) and using the “fling-step” correction with $T_1 = 30\,\mathrm{sec}$ and $T_2 = 35$, 40, 45, and 50 sec.

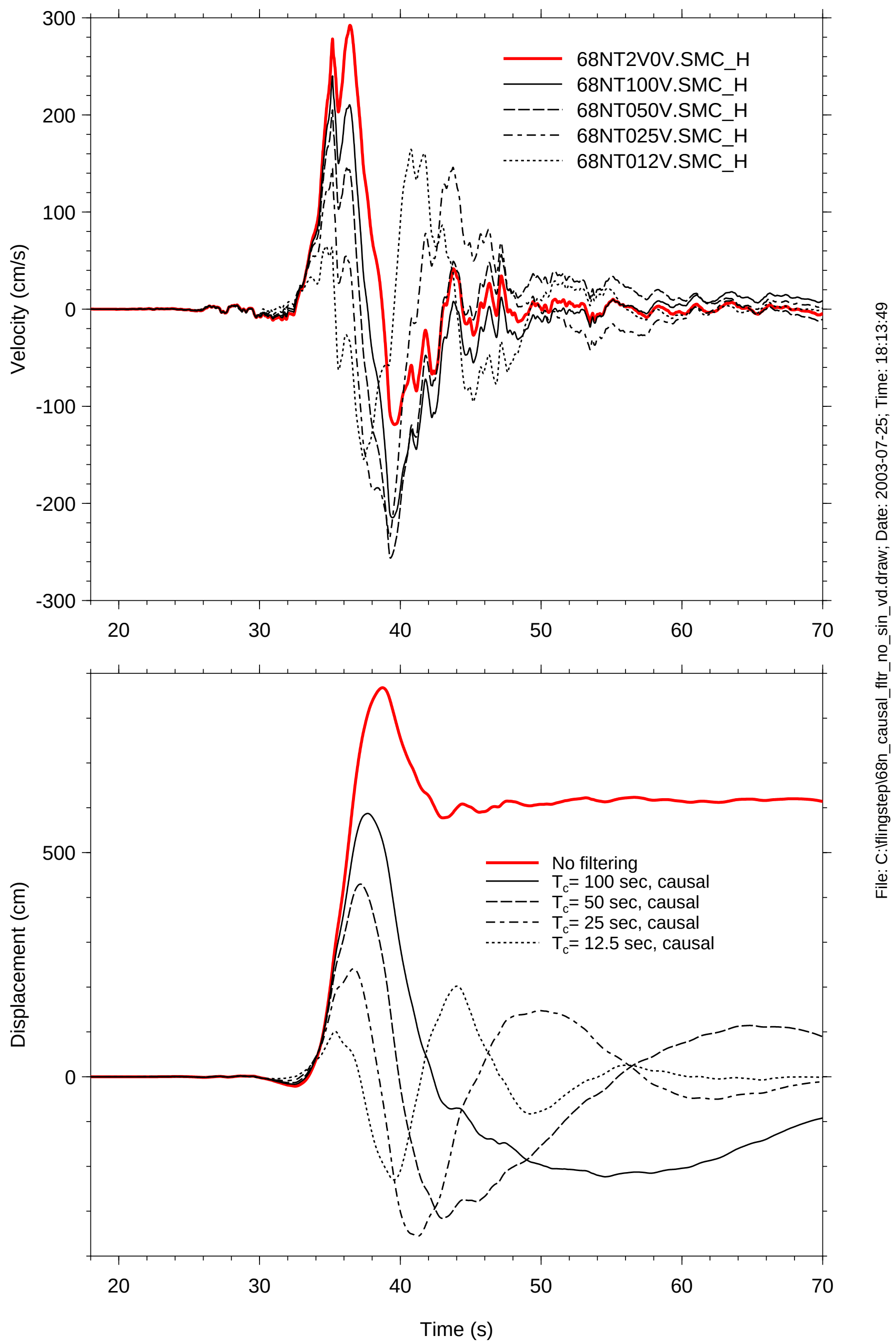

Figure 2. The velocity and displacement time series derived from the TCU068 recording, using the "v0" correction (fit a straightline to the later part of velocity and remove a step in acceleration with amplitude equal to the slope of the fitted line, starting at the time given by the intersection of the fitted line and the zero line in velocity; the result is labeled "No filtering") and using low-cut causal Butterworth filters, with filter corner periods of 12.5, 25, 50, and 100 sec.

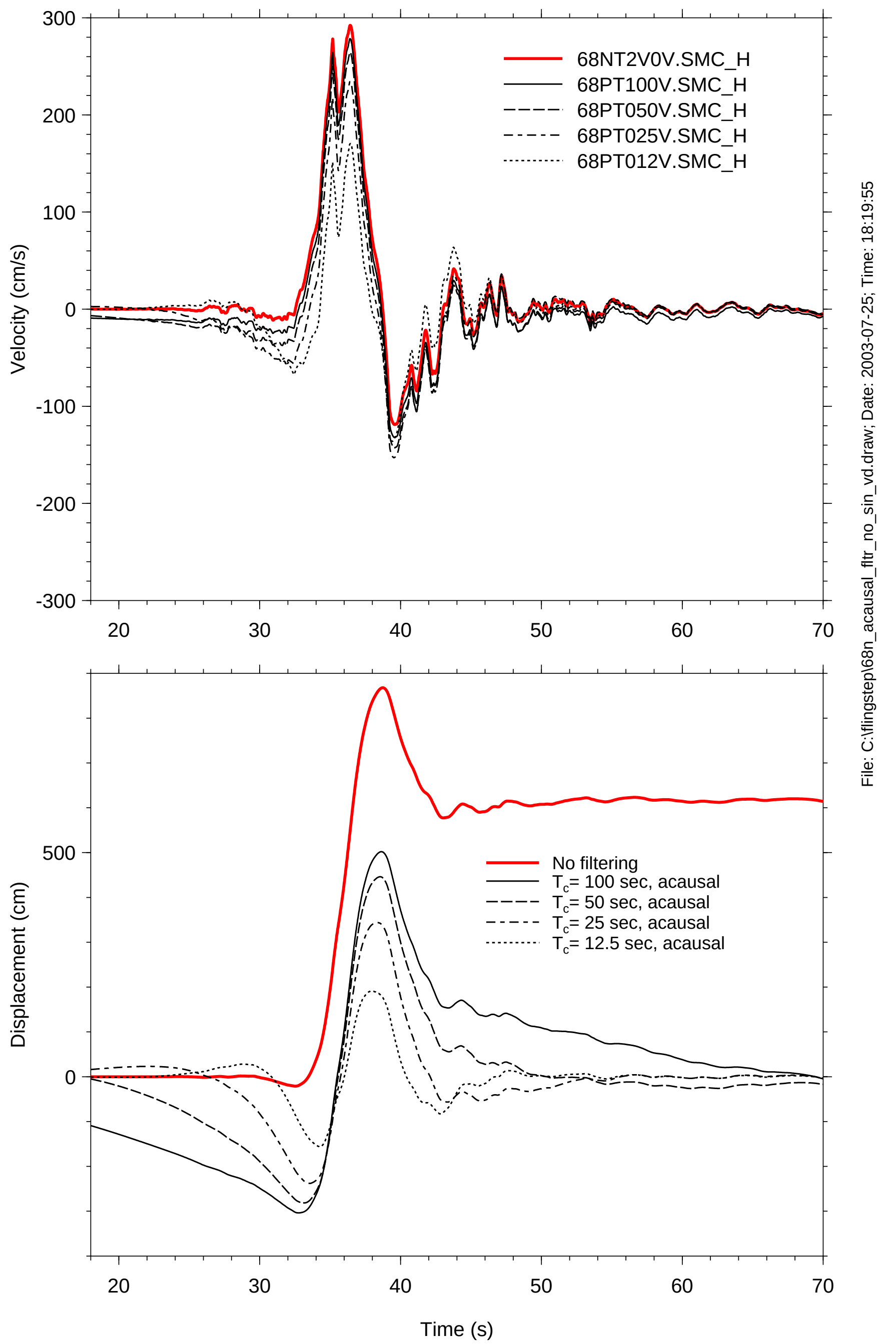

Figure 3. The velocity and displacement time series derived from the TCU068 recording, using the “v0” correction (fit a straightline to the later part of velocity and remove a step in acceleration with amplitude equal to the slope of the fitted line, starting at the time given by the intersection of the fitted line and the zero line in velocity; the result is labeled “No filtering”) and using low-cut acausal Butterworth filters, with filter corner periods of 12.5, 25, 50, and 100 sec.

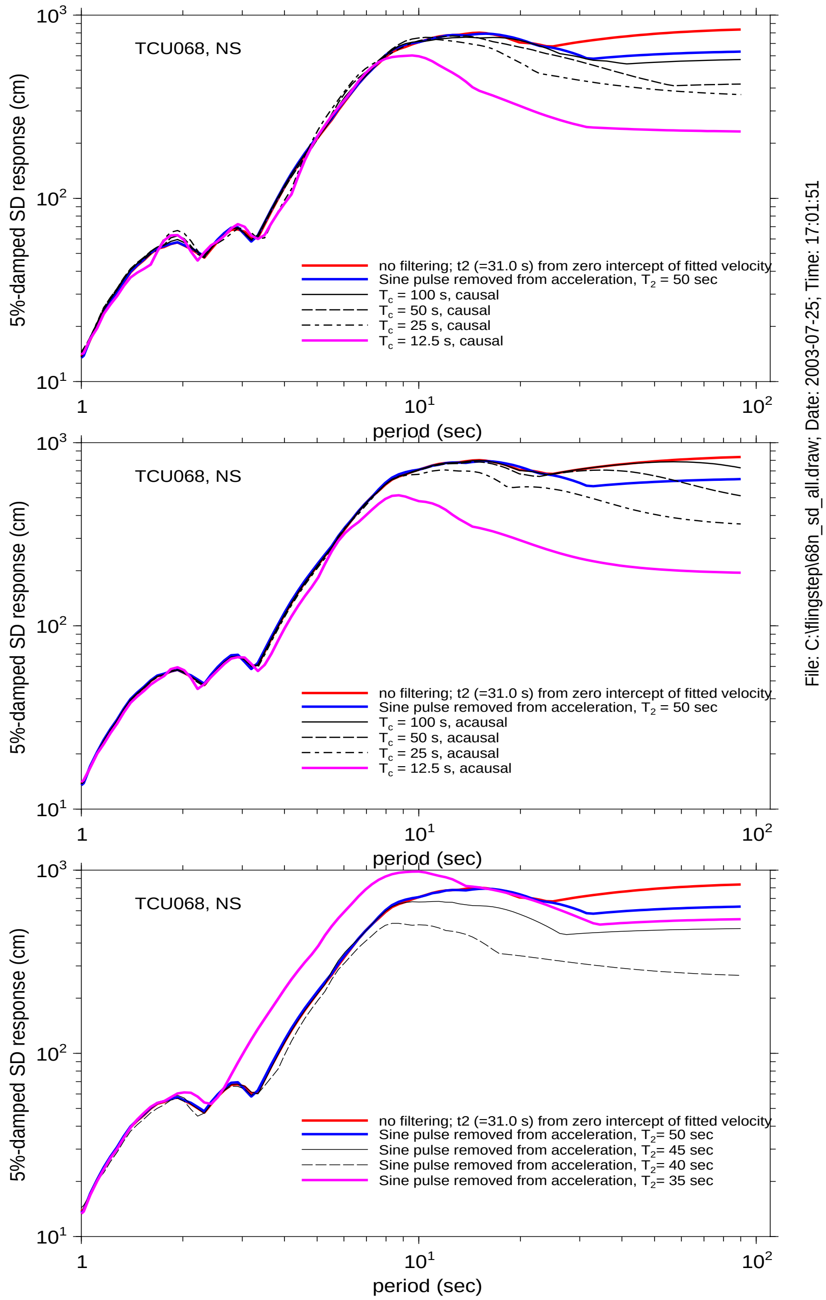

Figure 4. 5%-damped relative displacement response spectra for the time series processed using the "fling-step" removal and using causal and acausal filters.

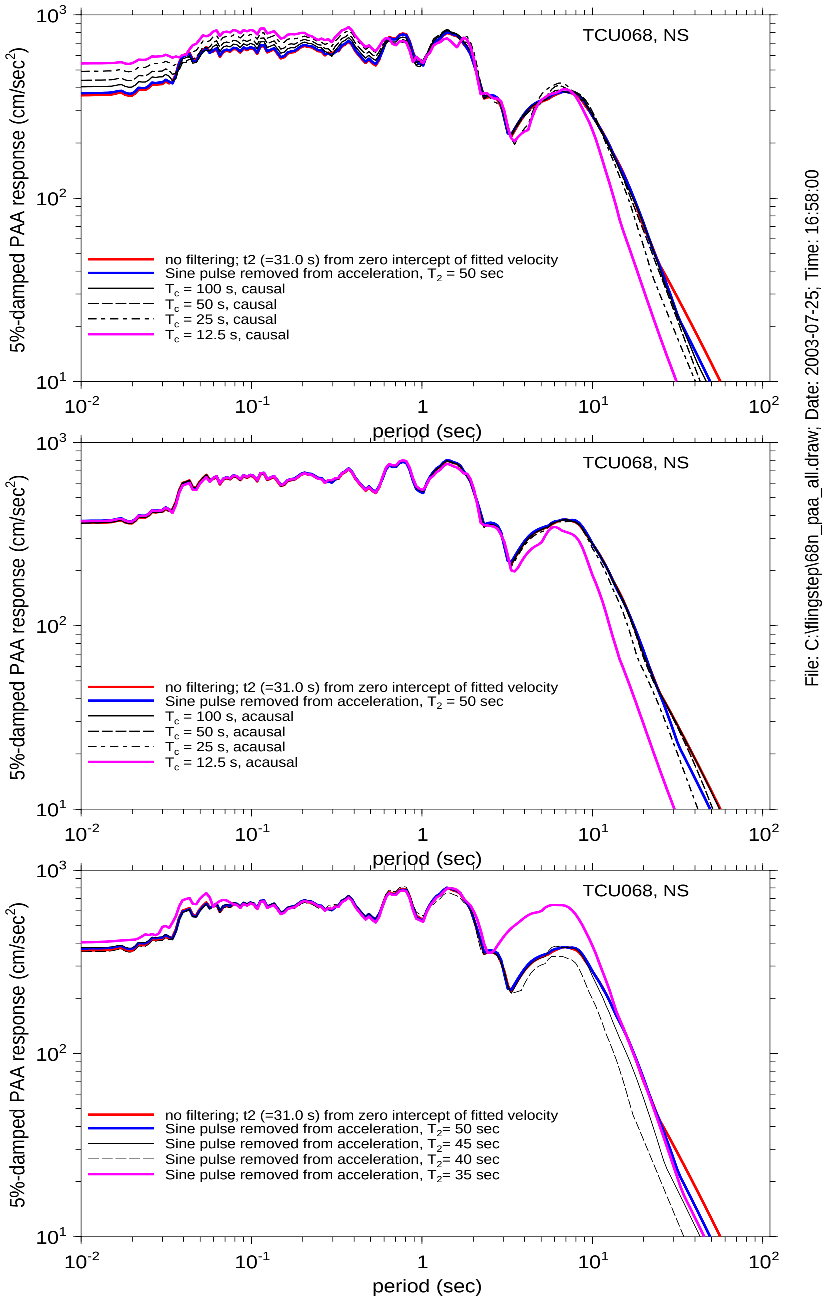

Figure 5. 5%-damped pseudo absolute acceleration response spectra for the time series processed using the "fling-step" removal and using causal and acausal filters.

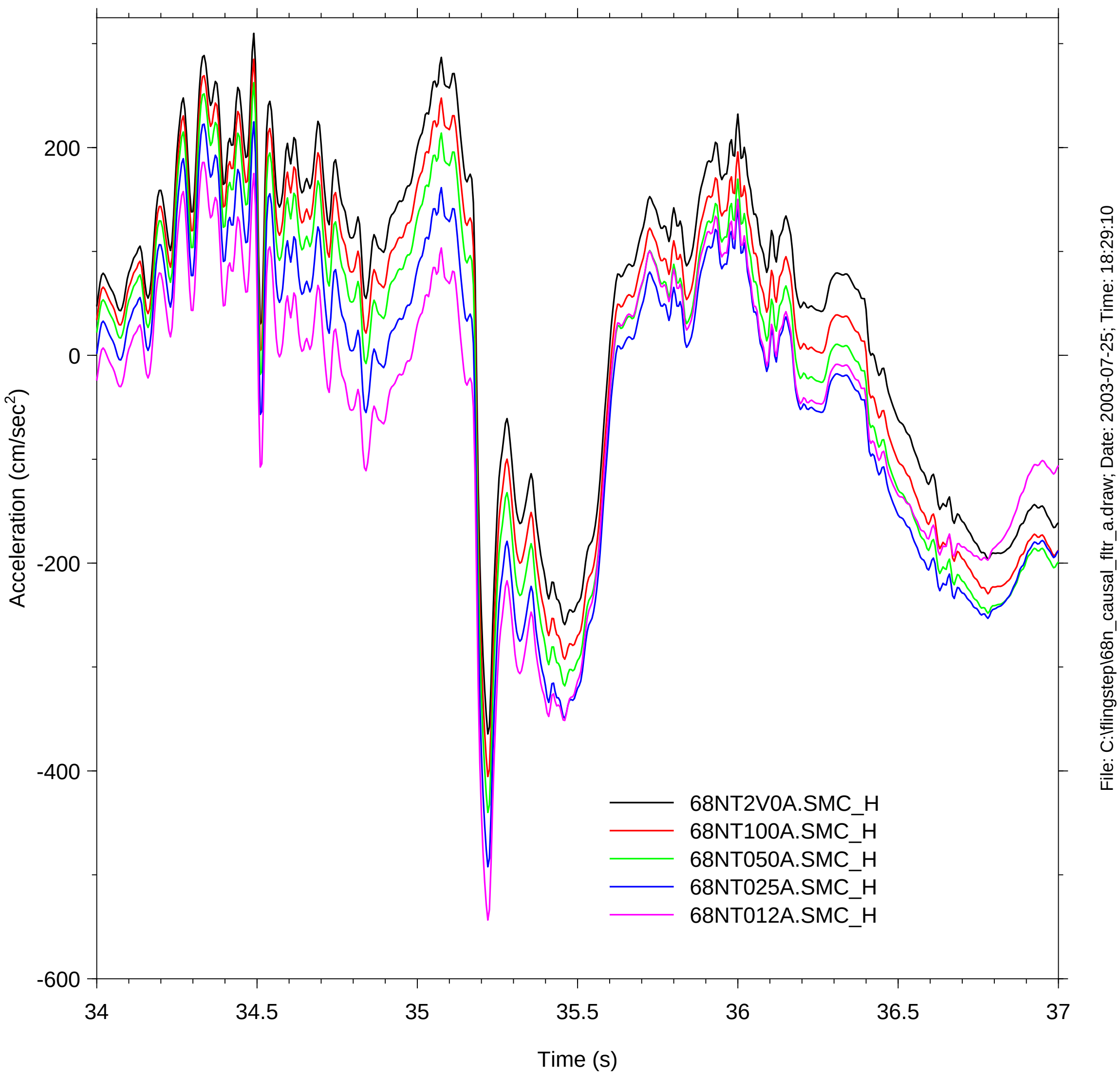

Figure 6. Acceleration time series after applying low-cut causal Butterworth filters at an expanded time scale for the regio of largest accelerations. This shows the surprising sensitivity of high frequencies to large corner periods when using a causal filter; a comparable plot using acausal filter shows little difference for the time series obtained using different corner periods.