A PROCEDURE FOR THE ACCELEROGRAM PROCESSING

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SUMMARY

The digitized analog strong-motion earthquake records should be processed in such a way that most of the physically real signals are preserved while the high frequency errors due to transduction nonlinearity and the low frequency digitization noise are eliminated. For the elimination of the low frequency noise a method based on high-pass recursive filtering of the velocity trace is proposed. The method utilizes a rational determination of the low frequency cut-off level, does not exhibit Gibbs phenomenon, preserves the correspondence between acceleration, velocity and displacement traces.

INTRODUCTION

The usable frequency band of a digitized strong motion accelerogram is inherently restricted by the combined noise of transducing, digitizing and processing, and thus for proper processing and utilization of accelerograms, various corrections have to be incorporated and the limits of this band have to be assessed. Various correction procedures have been proposed by many investigators such as: Housner (1947), Amin and Ang (1966), Hudson, Nigam and Trifunac (1969), Trifunac, Udwadia and Brady (1971), Trifunac and Lee (1973), Newmark (1973), Taheri (1977), Kurata, Iai and Tsuchida (1978), Trifunac and Lee (1979), Sunder (1980). Amin and Ang (1966) assume that the base line of the acceleration trace is of the polynomial form and basically add a time dependent second order polynomial to the acceleration with the coefficients of the polynomial computed so as to minimize the mean square of the velocity.

The method utilized by the Port and Harbour Research Institute (Kurata, Iai Tsuchida 1978), employs frequency domain instrument correction and bandpass filtering procedures. The procedure developed in California Institute of Technology(Trifunac, Udwadia and Brady, 1971; Trifunac and Lee, 1973) is based on bandpass filtering in the time domain. Another time domain procedure proposed by Sunder (1980) utilizes optimal finite impulse response linear phase differentiators for the instrument correction and infinite impulse response nonlinear phase elliptic filters for the bandpass filtering of the data.

PROPOSED PROCEDURE

The processing procedure developed herein generally borrows from the procedure proposed by Trifunac, Udwadia and Brady (1971) but differs in : (1) the use of rational physical methods in the assessment of the low frequency reliability limit, (2) the use of Butterworth type recursive filters for low frequency filtering of the data, and thereby eliminating the so called ringing (Gibbs phenomenon) effect associated with the Ormsby type filters (Kanasewich, 1973), and (3) carrying out the basic filtering operations on the velocity trace and then obtaining the acceleration and displacement traces through differentiation and integration to preserve the correspondance between these traces.

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The basic steps of this processing procedure are illustrated in Fig.1 and can be summarized as follows :

Digitization (step 1) The contact copies of the original trace are digitized

Raw Acceleration (step 2) These unequally spaced data are interpolated to produce equi-spaced data (currently set at 0.01 sec time intervals). This set forms the so called uncorrected acceleration" data.

High Frequency Filtering of the Raw Acceleration (step 3) To filter out the high frequency noise introduced by the digitization and interpolation steps, which may create undesirable amplifications during transduction error correction, an Ormsby type non-recursive (truncated impulse response) digital filter is employed. The currently adopted values for the cut-off and cut-off termination frequencies are 23.0 and 25.0 hz. The effect of this filtering on a random data sample is illustrated in Fig.2

Transduction Error Correction (step 4) The transduction error is corrected through differentiation of the instrument response and reconstruction on the basis of the governing differential equation (Trifunac, et al., 1971). For this correction the current data spacing is divided by two (i.e.0.005s) to increase accuracy.

Least Square Fitting a Straight Line (step 5) A straight line is least square fitted to the acceleration trace and the acceleration is adjusted accordingly.

Integration to Velocity (step 6) The resulting acceleration is integrated to obtain the velocity trace assuming zero initial velocity.

Determination of the Low Frequency Limit (step 7) For the determination of the low frequency limit of the reliability of the data beyond which the low frequency filtering will be conducted, following theoretical shape of the Near Field Fourier Amplitude Spectrum of the ground acceleration, proposed by Brune (1970) is utilized.

$$A(f) = V_o . f . \sqrt{f^2 + f_T^2} \quad ; \quad f < f_T \qquad (1)$$

where, V_o, is the maximum near field velocity (at the fault on the base rock), and f_T, is the corner frequency that corresponds to a wavelength in the orders of the fault rupture length.

The low frequency limit of the Eq.1 indicates a behavior directly proportional to the frequency. The foregoing approach is illustrated in Fig.3 where the dashed 45° line representing the low frequency behavior of Eq.1 is superposed on the uncorrected Fourier amplitude spectrum of the SOOE component of the El Centro recording of the 1940 Imperial Valley Earthquake indicating the frequency about which the low frequency noise starts to emerge.

Low Frequency Filtering of the Velocity (step 8) Low frequency filtering is carried out on the velocity trace for the elimination of the inherent low frequency noise. A second order Butterworth type recursive low frequency filter is employed (Kanasewich, 1973)

It should be noted that Butterworth type recursive filters (Kanasewich, 1973) do not incorporate the "Gibbs Phenomenon" associated with the Ormsby type truncted impulse response filters. Gibbs phenomenon exhibits itself with a dominant periodicity, so-called ringing, around the filter cut-off frequency in the displacement trace of especially small amplitude motions. Butterworth filters respond only in the positive time and they do not have linear phase spectra. To obtain zero phase filtering with recursion: (1) the input data is filtered in the normal manner to produce a first output, (2) this output is then reversed in time and filtered again to produce a second output, and (3) this output, reversed in time, yields the desired filtered output with no phase errors. The effect of this filtering on the same random data sample utilized in Fig.2 is illustrated in Fig.4.

Least Square Fit of a Straight Line to Velocity (step 9) A straight line is least square fitted to the low frequency filtered velocity and adjusted accordingly.

Integrate For Displacement (step 10) The velocity trace is integrated to obtain the displacement, assuming zero initial condition.

Corrected Displacement Trace (step 11) A straight line is least square fitted to this displacement and adjusted accordingly to obtain the corrected displacement data.

Corrected Velocity Trace (step 12) The slope of this straight line is added to the velocity of the previous step to yield the corrected velocity data.

Differentiate for Acceleration (step 13) The corrected velocity is differentiated for acceleration by using a finite impulse response type linear phase digital differential filter (McClellan et al., 1973).

Anti-Aliasing Filtering (step 14) The acceleration trace ise high frequency filtered for anti-aliasing, using the Ormsby filter with the same filtering limits, as of step 3.

Corrected Acceleration (step 15) Step 14 yields the corrected acceleration for spectral analysis.

SENSITIVITY CONSIDERATIONS

The displacement, velocity and acceleration time histories of the corrected ground motion, and the shape and the limits of relevant spectra are sensitive to various parameters. The following sub-sections identify and elaborate on some specific sensitivity analyses.

Sensitivity to the Cut-off Frequency of the Low Frequency Filter The cut-off frequency used in the recursive low frequency filtering of the data essentially effects the resultant displacement trace of motion. Figure 5 depicts the sensitivity of the displacement trace of the S00E component of the El Centro recording of the 1940 Imperial Valley Earthquake to the cut-off frequency. The cut-off frequency has assigned values of 0.06, 0.10, 0.13 and 0.16 Hz. Note that the cut-off frequency of 0.16 Hz is the accepted value for this record.

Sensitivity to the Cut-off Frequency of the High Frequency Filter The maximum amplitude of the corrected ground acceleration and, in parallel, the peudo spectral accelerations corresponding to the high frequency spectral regions exhibit sensitivity to the cut-off frequency of the high frequency of the high frequency Ormsby filter utilized in processing.

A tableof corrected acceleration, velocity and displacement maxima and the pseudo spectral accelerations at 25 Hz and 34 Hz spectral frequency of the S00E component of the El Centro recording of the Imperial Valley Earthquake corresponding to the high frequency filter cut-off and cut-off termination frequencies of 23/25, 33/35 and 48/50 Hz are provided in Table 1. A similar table for the Bonds Corner and El Centro Station 8 records of the October 15, 1979 Imperial Valley Earthquake is provided by Brady(1980) utilizing exactly the same filter characteristics with the conclusion that the filter cut-off and cut-off termination frequencies have only marginal effects on the corrected time history maxima of the motion. Although the results documented herein substantiates a somewhat more sensitivity of the peak ground acceleration to the filter cut-off frequency characteristics, both findings does not warrant any general conclusions apart from indicating some instrument and event-specific phenomena.

Sensitivity to the Sampling (Interpolation) Interval As it can be assessed from Table 2, where the corrected motion maxima and the pseudo spectral accelerations for 25 Hz and 34 Hz spectral frequencies are given for sampling intervals of 0.005, 0.010 and 0.020 seconds, the time history and the spectral values are not sensitive to the reasonable variations of the sampling interval with the exception of the acceleration values which indicates some increase with decreasing sampling intervals. This finding is also reported in Brady (1980).

CONCLUSIONS

A strong-motion accelerogram processing procedure is described. The procedure: (1) introduces a rational and record-specific technique of the low frequency filter cut-off frequency determination, (2) utilizes Butterworth type recursive filter for the low frequency filter to alleviate the Gibbs phenomenon, (3) utilizes an Ormsby type high frequency filter for the elimination of the high frequency noise, and (4) carries out the filtering operations on the velocity trace to preserve the correspondance between acceleration and displacement traces.

Sensitivity analyses indicate considerable sensitivity of the corrected displacement traces to the choice of the cut-off frequency of the low frequency filter which necessitates careful and record-specific considerations for the selection of the cut-off frequency.

Peak accelerations and the high frequency pseudo spectral accelerations are found to indicate sensitivity to the selection of the sampling interval and the high frequency filter cut-off frequency values. However this finding is based on a specific-record and may need further substantiation for generality.

Although it has not been repeated herein, the comparative applications of this procedure and that provided by Trifunac and Lee (1972) indicate excellent agreement of the acceleration and velocity traces for the same filter cut-off values. However the displacement traces indicate different amplitude, frequency content and phase characteristics.

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TABLE 1. SENSITIVITY TO THE CUT-OFF FREQUENCY OF THE HIGH FREQUENCY FILTER IMPERIAL VALLEY EARTHQUAKE, MAY,18,1940-2037 PST
EL CENTRO SITE IMPERIAL VALLEY IRRIGATION DISTRICT
SOOE COMPONENT ($f_1 = 0.16$Hz, $\Delta t = 0.01$ sec)

HIGH FREQUENCY FILTER		C O R R E C T E D			P S A	
f_c (Hz)	f_t (Hz)	ACCELERATION (gal)	VELOCITY (cm/sec)	DISPLACEMENT (cm)	25 Hz (gal)	34 Hz (gal)
23	25	357.990	-33.340	7.546	532.922	404.707
33	35	426.645	-35.492	7.546	674.737	571.748
48	50	428.726	-35.454	7.547	671.274	533.766

TABLE 2. SENSITIVITY TO THE SAMPLING INTERPOLATION INTERVAL
DENIZLI EARTHQUAKE - AUGUST 19,1976, 0112 ST.
DENIZLI, COMPONENT - NS

SAMPLING INTERVAL (sec)	C O R R E C T E D			P S A	
	ACCELERATION (gal)	VELOCITY (cm/sec)	DISPLACEMENT (cm)	25 Hz (gal)	34 Hz (gal)
0.005	324.427	22.227	-2.700	344.997	332.683
0.010	322.674	22.219	-2.700	336.463	327.730
0.020	318.559	22.140	-2.670	320.930	318.160

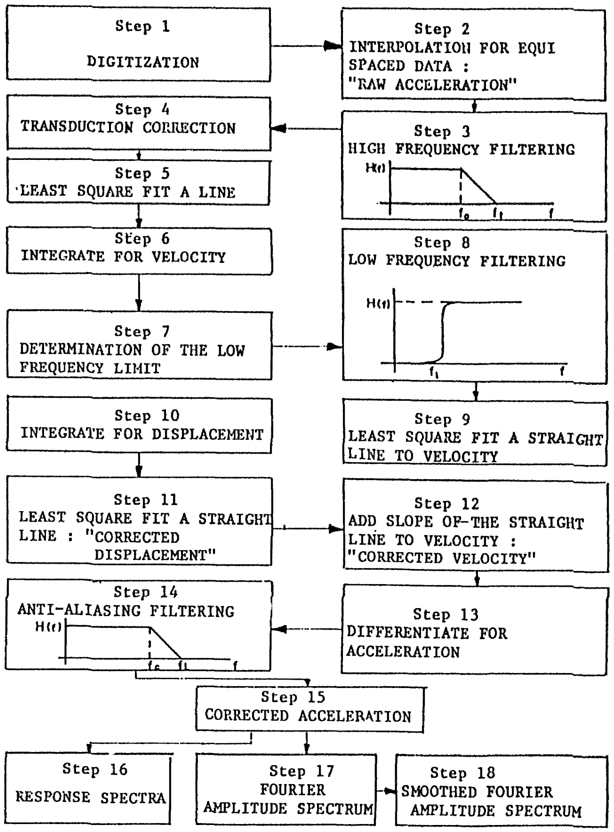
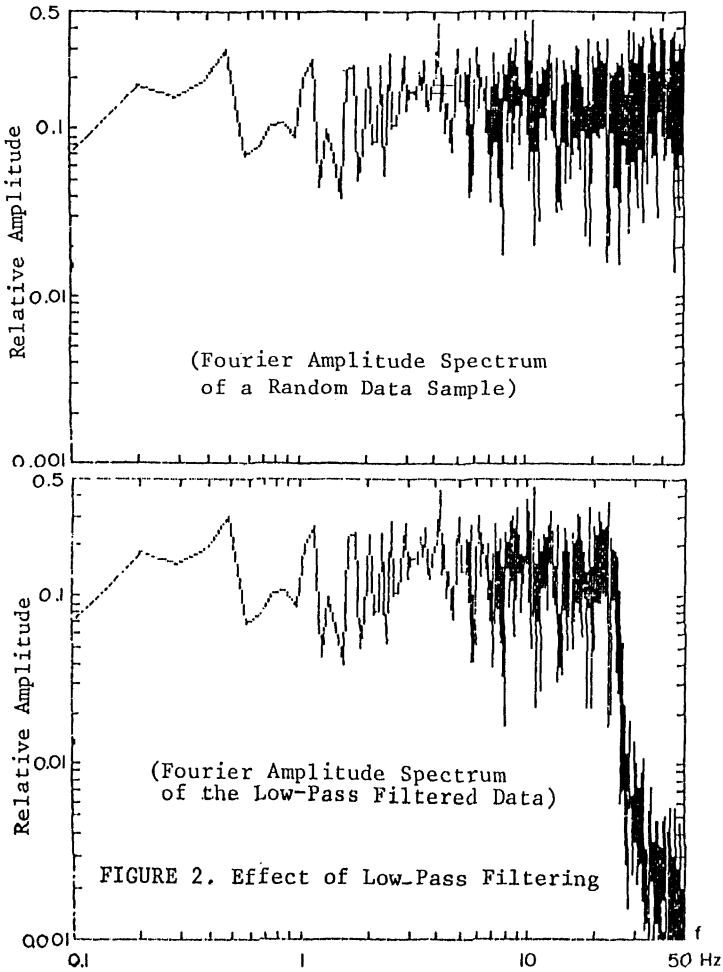


FIGURE 1. Flowchart of the Processing Procedure



(Fourier Amplitude Spectrum of a Random Data Sample)

(Fourier Amplitude Spectrum of the Low-Pass Filtered Data)

FIGURE 2. Effect of Low-Pass Filtering

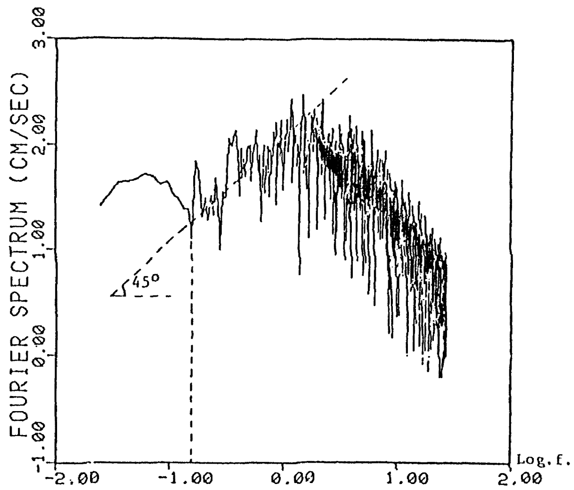


FIGURE 3. Low Frequency Reliability Limit of the El-Centro Acceleration Data

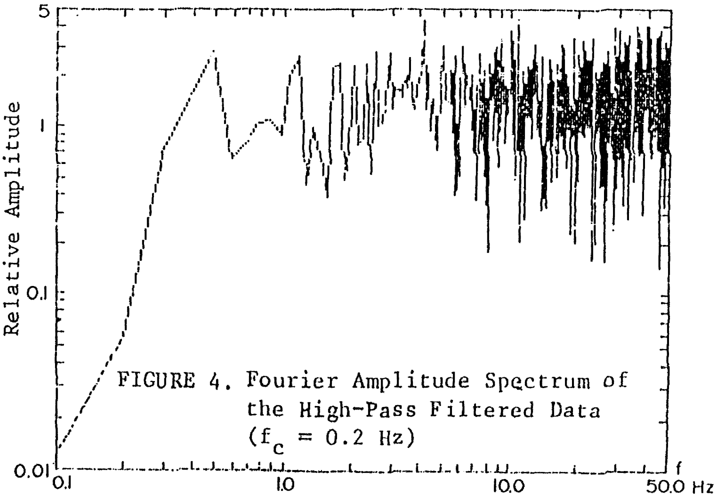


FIGURE 4. Fourier Amplitude Spectrum of the High-Pass Filtered Data ($f_c = 0.2$ Hz)

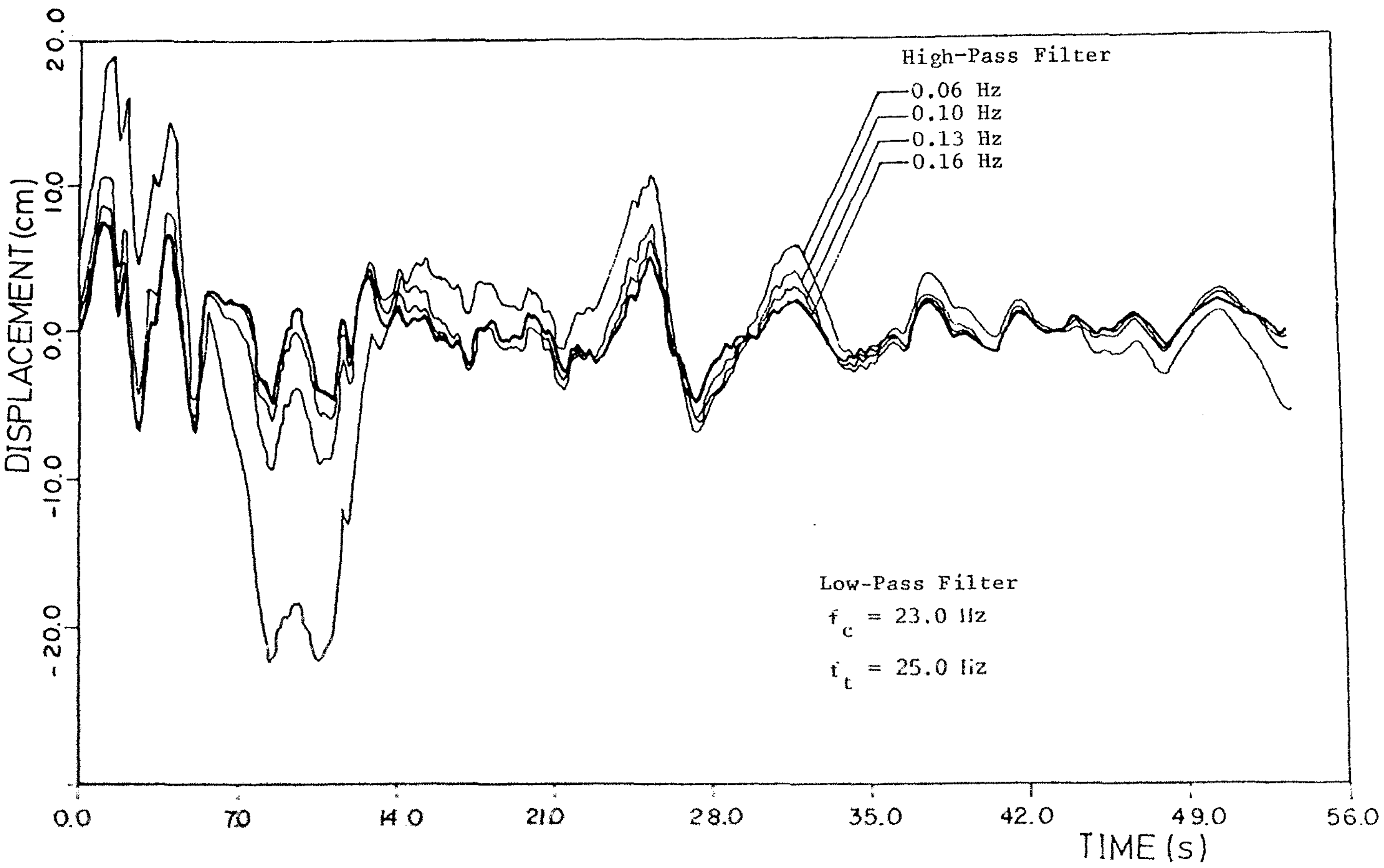


FIGURE 5. Corrected Ground Displacement Traces For Various Low Frequency Cut-Off Limits Imperial Valley Earthquake-May 18,1940 - 2037 PST El Centro Site Imperial Valley Irrigation District, Comp : S00E