IMPROVEMENTS IN STRONG-MOTION DATA PROCESSING PROCEDURES

A.M. Converse (I)
A.G. Brady (II)
W.B. Joyner (III)
Presenting Author: A.G. Brady

SUMMARY

The computer programs used at the United States Geological Survey (USGS) for processing digitized strong-motion accelerograms have been changing in recent years. The current series of programs, collectively called AGRAM programs, provide better accuracy, versatility, speed, and transportability than programs that had been used in the past.

INTRODUCTION

The AGRAM programs perform the routine computer processing used in preparing the data reports published by the USGS regarding analog strong-motion accelerograms. The programs are also used for nonstandard analysis. Although they were established to process accelerograms that have been digitized by the automatic trace-following laser equipment at IOM/TOWILL, they will accept data from other sources as well.

The AGRAM programs evolved from a series of programs, collectively called PHASE programs, that were developed at the Earthquake Engineering Research Laboratory of the California Institute of Technology during the years 1968 to 1972. Since then, the USGS versions of the programs have often been modified to improve numerical techniques, to adapt the code to different computers, and to accommodate different types of incoming data. They have also been revised to separate the processing functions into smaller and more independent programs and to manipulate intermediate data files that conform to a file organization required by the National Strong-Motion Data Center of the USGS. The user's manual for the AGRAM programs (Ref. 1) includes a section with each program description that compares the processing provided by the AGRAM program to the processing once provided by its PHASE counterpart. The monograph cited as Ref. 2 gives an overview of the PHASE programs.

Recent improvements to the programs provide better instrument correction, maximum use of densely digitized data, and freedom to choose interactively from a variety of long-period filtering schemes. The programs are still in the development process; many of the options they provide have yet to be evaluated and many other features intended for

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(I) Computer Specialist, U.S. Geological Survey, Menlo Park, California, USA.
(II) Physical Scientist, U.S. Geological Survey, Menlo Park, California, USA.
(III) Geophysicist, U.S. Geological Survey, Menlo Park, California, USA.

the programs have yet to be implemented. With continued support and further development, however, the programs will evolve into a comprehensive series of relatively transportable computer programs suitable for use on computers having FORTRAN 77 compilers and moderate amounts of addressable memory.

PROCESSING STEPS

The contents of a tape written at the digitizing facility are processed by the AGRAM programs at the National Strong Motion Data Center at the USGS offices in Menlo Park, California. First, the BUTTER program is used to rejoin separately digitized frames of an accelerogram into one continuous record. The SCALE program then scales the data to represent time and acceleration rather than digitizer units. Next, the HIFRIC program interpolates the data, applies an instrument correction and a high-cut filter to the data. The CORAVD program integrates the HIFRIC results to obtain velocity and displacement and optionally performs a linear base line correction or filters out long-period content. The PHASE3 and PHASE4 programs perform spectral analyses on the CORAVD results. Support programs included with the AGRAM package can be used at various stages of this process. The support programs manipulate the intermediate AGRAM data files and perform plotting, display, and reformatting functions.

The most significant recent changes in numerical techniques have been made in the procedures in HIFRIC and CORAVD. The spectral analysis programs may be rewritten in the near future to use more up-to-date numerical techniques and new versions may be available by the time this paper is presented. The new versions will have new names, RSPECT (Response spectra) and FSPECT (Fourier spectra), to indicate that they are quite different from their PHASE3 and 4 counterparts.

HIFRIC PROCESSING

HIFRIC applies interpolation, instrument correction and a high-cut filter to SCALE data. Options provide alternative instrument-correcting and filtering algorithms. With the standard option, HIFRIC applies a time-domain algorithm; with another option it applies a frequency domain algorithm; and with a third option the instrument correction and filter are suppressed altogether, providing interpolated, uncorrected data. The time-domain instrument-correcting algorithm was written by Michael Raugh (Ref.3), and the frequency-domain instrument-correction algorithm was written by the third author of this paper.

Both correcting algorithms apply a second-order differential equation representing motion of a viscously-damped, one-degree-of-freedom oscillator. The two algorithms produce almost identical results when applied to densely digitized data from analog film recorders and when using standard filter parameters, but the standard time-domain method runs faster than the frequency domain method.

With the time domain algorithm, the data are interpolated to an even sampling of 600 samples per second (sps) which is the approximate sampling density provided by the IOM/TOWILL digitizing equipment. Next, the frequencies from zero to Nyquist, 300 Hz, are divided into six equal-width bands. The first band, from 0 to 50 Hz, is that in which instrument correction is performed. The second, from 50 to 100 Hz, is a transition band providing a cosine taper from full to zero frequency response. The remaining bands, from 100 to 300 Hz, contain near-zero frequency response. After filtering, the data are decimated by removing 2 out of every 3 points, reducing the sampling density from 600 sps to 200 sps.

With the frequency domain method, equal-length segments of densely interpolated time series data are transformed to the frequency domain with a Fast Fourier Transform. Transformed values are instrument corrected, filtered, then transformed back to the time domain. The separately filtered segments of data are fitted back together using an "overlap-add" method (Ref. 4).

More accurate approximations of the derivatives required by the damped harmonic oscillator equation are used in HIFRIC than the centered-difference method for differentiation that had been used in earilier programs such as PHASE2. The standard HIFIRC method incorporates Fourier differentiation (i.e., $\frac{d}{dt} e^{i\omega t} = i\omega e^{i\omega t}$) in convolution operators, which are applied in the time-domain, to approximate the first and second derivatives required. The alternative HIFRIC method applies Fourier differentiation in the frequency domain.

The high-cut filters used in HIFRIC are also different from the Ormsby convolution that had been used in the past. In HIFRIC with the time-domain method, a filter is incorporated in the same convolutions that calculate the derivatives in the time domain. With the alternative method, the spectrum is multiplied by a cosine taper between the cutoff and roll-off termination frequencies and is set to zero above that.

Standard HIFRIC process:

1) Calculate weights for three convolution operators. Each operator has 61 weights which will span 0.1 second of 600 sps data.
2) Read input data that have been prepared by the SCALE program or its equivalent. These data, $y(t)$, represent measured, scaled instrument response and are equal to $-\omega^2 x(t)$, where $x(t)$ is the displacement of the mass relative to the instrument case and ω is the natural frequency of the instrument.
3) Interpolate linearly to 600 sps.
4) Apply convolution operators centered at every third sample of the 600 sps interpolated input data to compute z, z', and z'' at 200 sps, where z is a high-cut filtered version of the input data, y. Combine z and its two derivatives according to the damped harmonic oscillator equation, where

corrected acceleration = $z + z'2n/\omega + z''/\omega^2$

n is the fraction of critical damping of the instrument, and
ω is the natural frequency of the instrument in radians per second.

This 4th step simultaneously provides:

- instrument correction between 0 and 50 Hz;
- high-cut filter with cosine taper between 50 and 100 Hz, and stop band from 100 to 300 Hz;
- decimation to 200 sps.

The high-cut filter is applied to prevent aliasing when the data eare decimated to 200 sps.

CORAVD PROCESSING

CORAVD calculates velocity and displacement from acceleration and optionally performs baseline correction of two possible types. One option makes a linear correction to the velocity and another option filters long periods from acceleration and velocity.

Triggered analog records do not begin instantaneously with the beginning of the earthquake motion, but only after the motion has become strong enough to trigger the recorder. The linear baseline correction option establishes a reasonable value for the acceleration and velocity at the beginning of such a record provided that some portion (or all) of the first approximation of velocity has a reasonably linear trend. The fitted line is subtracted from the velocity and a constant, equal to the slope of the line, is subtracted from the acceleration. The portion of the velocity to be fitted is specified as a run parameter. No attempt is made to estimate an initial value for the displacement. The displacement is calculated from the velocity after the velocity has been corrected.

Digital recorders with pre-event memory show, in their records, several seconds of motion that occurred before triggering. Initial values of zero for acceleration, velocity and displacement are appropriate for these records (provided the recording system operated as designed) and the linear correction is generally not required.

The linear correction gives good results for some accurately digitized records, but many records will require that long periods be filtered from the data before reasonable displacements can be calculated or before reasonable spectra can be calculated in the PHASE3 and 4 programs. For routine processing a bidirectional Butterworth filter is used, and several other filter algorithms are available for use in special studies.

When filtering is used in CORAVD, each time-series is filtered just once. Velocity is calculated from acceleration before acceleration is filtered; displacement is calculated from the filtered velocity and is not refiltered itself. Earlier programs such as PHASE2 had calculated velocity from a filtered version of the acceleration, filtered the velocity, calculated displacement from the filtered velocity and filtered the displacement. This refiltereing of a time-series determined from an already filtered time-series magnified any distortion in the filter, and is avoided in CORAVD. CORAVD also uses the significantly faster bidirectional Butterworth filter algorithm rather than the Ormsby filter. A brief discussion of the advantages of the Butterworth filter, in addition to its increased speed, is given in Ref. 5.

By default, CORAVD does no filtering and applies the linear baseline correction, fitting the entire length of the velocity time series. Users must reconsider for each particular record whether or not such processing is appropriate. The need for different handling will often show in a plot of the results from CORAVD where long period waves that were not apparent in the uncorrected acceleration can be seen in the integrated velocity or displacement or when the displacement at the end of the plot is much different than could really have occurred.

Standard CORAVD process:

1) Integrate acceleration to compute velocity. Use trapezoidal integration and use zero as the initial velocity.
2) Subtract the linear least squares fit of the velocity from the velocity to establish an initial value for the velocity. Fit the entire velocity time-series unless user has specified that just a portion of the velocity, maybe just the quiet period at the end of the time-series, be used.
3) Subtract a constant from the acceleration, the constant being the slope of the line fitted to velocity.
4) Filter low frequencies from velocity and acceleration, if necessary. Use the same filter parameters for both.
5) Integrate velocity to compute displacement, using zero as the initial displacement.

REFERENCES

(1) Converse, A.M. (1983). AGRAM: a Series of Computer Programs for Processing Digitized Strong-Motion Accelerograms; Version 1.0: USGS Open-File report Number 83-276, USGS, Menlo Park, CA 94024. 147 pages.

(2) Hudson, D.E. (1979). Reading and Interpreting Strong Motion Accelerograms: Earthquake Engineering Research Institute, 2620 Telegraph Avenue, Berkeley, CA 94704. 112 pages.

(3) Raugh, M.R. (1981). Procedures for Analysis of Strong-motion Records, (abs.): Earthquake Notes, Vol. 52, No. 1.

(4) Oppenheim, A.V., and Schafer, R.W. (1975). Digital Signal Processing: Prentice-Hall.

(5) Fletcher, J.B.; Brady, A.G.; and Hanks, T.C. (1980). Strong-Motion Accelerograms of the Oroville, Califoria, Aftershocks: Data Processing and the Aftershock of 0350 August 6, 1975: Bulletin of the Seismological Society of America, vol. 70, No. 1, pp. 243-267.