Copyright © 1996 Elsevier Science Ltd
Paper No. 150. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

11 WCEE

CRITICAL EVALUATION OF VARIOUS STEPS IN PROCESSING OF STRONG MOTION DATA

ASHOK KUMAR, S. BASU AND B. CHANDRA

Department of Earthquake Engineering
University of Roorkee
Roorkee 247 667, INDIA

ABSTRACT

Strong motion data recorded either by digital or analog instruments must undergo corrections before these are given to users for different applications. The process may comprise of interpolation of unequally sampled sequence, decimation, transducer correction, band pass filtering and interpolation of corrected sequence to obtain desired sampling rate. Different authors have suggested different methods to perform the above processing steps. In this paper, comparison and evaluation of steps are done by taking response spectra of output of each step. Input of each step is taken as time history of three commonly used earthquakes. Results of band limited and linear interpolation of non uniformly spaced and uniformly spaced samples are compared and drawbacks of linear interpolation are pointed out. Transducer correction in time domain and frequency domain for 200 SPS sequence and for 50 SPS sequence are compared and it is shown that frequency domain transducer correction is more reliable. Decimation by dropping of samples and through band limited decimation gave almost similar results. Also comparison of Butterworth, Ormsby and half cosine tapered filter gave almost similar results.

KEYWORDS

Accelerogram; band limited interpolation; linear interpolation; decimation; transducer correction; response spectra; band pass filter; Butterworth filter; half cosine filter; Ormsby filter

INTRODUCTION

For aseismic analysis and design of engineering structures, equipments and other life line systems, understanding the nature of earthquake ground motion and the resulting response is of prime importance. This can be achieved by recording the strong ground motion in the event of earthquakes on strong motion accelerographs. It is, therefore, important that information be extracted as accurately as possible from the records of accelerographs (known as accelerograms) and this be interpreted carefully.

There are two different types of accelerographs that are currently in use namely analog and digital. However, during recording, digitizing and processing of records of analog as well as digital accelerographs, signal gets transformed and noise creeps in the accelerogram. It is, therefore, essential to correct the accelerogram before it is given to users for different applications. This processing for correction may comprise of interpolation of unequally sampled data, decimation of data, transducer correction, band pass filtering and interpolation of corrected data to get the desired sampling rate. Several authors have suggested correction schemes using different methods to perform above steps (Kumar *et al* 1995; Erdik and Kubin, 1984; Khemici and Chiang, 1984; Lee and Trifunac, 1984). Conventionally, unequally sampled data as well as equally sampled data are linearly interpolated as and when required during the processing. Authors have shown elsewhere that linear interpolation introduces noise and distorts data (Kumar *et. al* 1995, Basu *et al.*, 1992, Kumar *et. al.* 1992, Kumar *et. al* 1994). Similarly, some authors have suggested to perform transducer correction in time domain (Erdik and Kubin, 1984; Lee and Trifunac 1979) whereas some others have chosen to use frequency domain approach (Kumar *et. al*, 1995; Khemici and Chiang, 1984). Different type of filters have been used by different authors to perform band pass filtering. Lee and Trifunac (1979) and Erdik and Kubin (1984) have used Ormsby filter in time domain, Khemici and Chiang (1984) have used half cosine tapered filter in frequency domain whereas Kumar *et. al* (1995) have used Butterworth filter in frequency domain. In this paper an attempt has been made to determine the affect of above mentioned approaches of different steps on acceleration response spectra of 2% damping for some of the most commonly used earthquake accelerograms.

INTERPOLATION OF NON UNIFORMLY SPACED DATA

Records of analog accelerographs which are digitized on semi automatic digitizers give data sequence which are unequally spaced. Such data are required to be interpolated to get an equally spaced sequence generally at 200 samples per second (SPS). Conventionally this is done by linearly interpolating the unequally spaced sequence. Kumar *et. al* (1992, 1995) have shown that the process of linear interpolation does not satisfy the fundamentals of digital signal processing as it introduces noise in the frequency band which was not defined in the original sequence (Nyquist frequency of unequally sampled data is defined as half of average sampling rate). This noise in the interpolated sequence is introduced at the cost of signal of the original band. Thus, linear interpolation not only introduces noise but also corrupts the signal. Kumar *et. al* (1992, 1995) have given a method (called band limited interpolation) to interpolate unequally spaced sampled sequence in a manner as to preserve the frequency content of original sequence. To compare the affect of two methods of interpolation on response spectra (2% damping), unequally spaced sequence of three earthquakes namely El Centro NS component of May 18, 1940 (EERL 70-20, File 1), Taft Lincoln School Tunnel N21E component of July 21, 1942 (EERL 70-20 File 20) and Uttarkashi S72W component recorded on Oct. 20, 1991 are interpolated to get the equally spaced sequence at 200 SPS. It may be noted that for El Centro earthquake, the average sampling rate of the unequally sampled sequence is 18.33 SPS whereas for Taft it is 17.62 SPS and for Uttarkashi it is 78.14 SPS. Thus, for band limited interpolation, cut off frequency of the low pass filter was taken as 9 Hz for El Centro, 8.5 Hz for Taft and 25 Hz for Uttarkashi. Response spectra of 2% damping determined for linearly interpolated sequence and band limited interpolated sequence for the three earthquakes are shown in Figs. 1-3. It may be seen that the two spectra differ substantially for the two cases and the peak difference is of the order of 38.74% (natural frequency 3.57 Hz) for El Centro, 63.15% (natural frequency 5.88 Hz) for Taft and 104.68% (natural frequency 3.33 Hz) for Uttarkashi. It may be noted that the average sampling rate of Uttarkashi accelerogram was substantially high but even then the peak difference is highest. In fact, the process of linear interpolation corrupts the signal at all frequencies and it is not possible to relate the error to any parameter.

DECIMATION OF DATA

During processing of accelerograms, sometimes it is required to reduce the sampling rate of the sequence in order to reduce computation particularly when processing is done in time domain. This is conventionally done by dropping samples. For example, if a sequence of 200 SPS is required to be decimated to 50 SPS then sample numbers first, fifth, ninth etc. are retained and the remaining samples are dropped. This

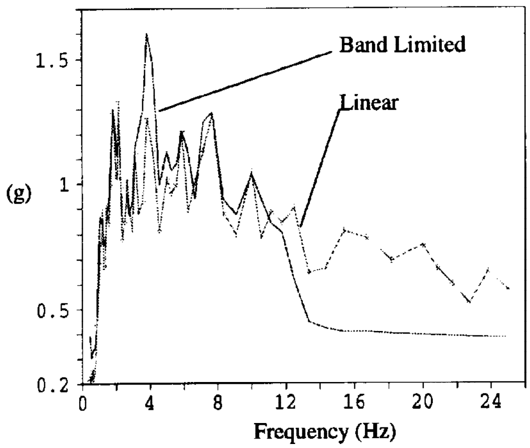

Fig. 1. Comparison of Spectra of El Centro Nonuniform Sequence Interpolated Linearly and by Band Limited Method

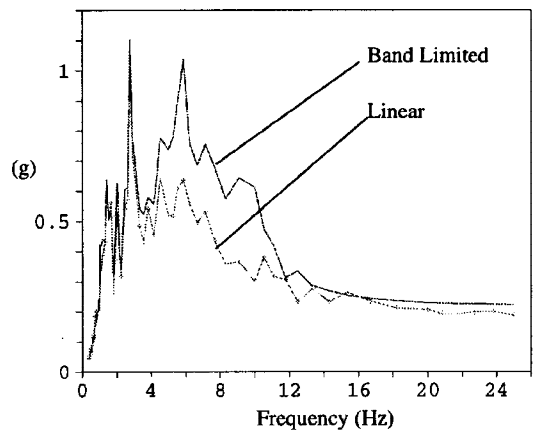

Fig. 2. Comparison of Spectra of Taft Non Uniform Sequence Interpolated linearly and by Band Limited Method

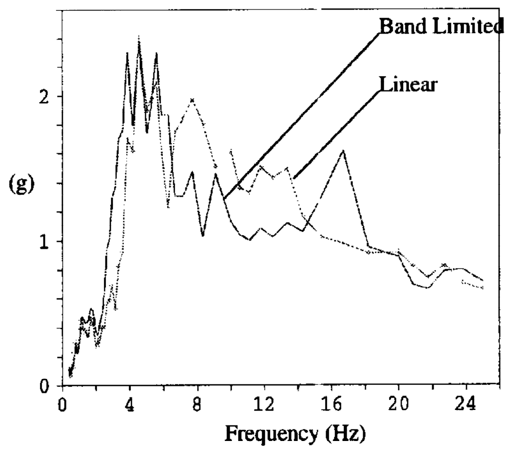

Fig. 3.Comparison of Spectra of Uttarkashi Nonuniform Sequence Interpolated Linearly and by Band Limited Method

method of decimation changes frequency content of the decimated sequence i.e. in the above cited example, the frequency contents of sequence for the band 0 to 25 Hz will be different for the original and decimated sequence. Kumar *et al.* (1995) has suggested a decimation scheme in frequency domain which preserves the frequency contents of the original sequence. This scheme works well only in case the decimation factor is an integer power of 2 and the sequence which is to be decimated has already been low pass filtered. To compare the two methods of decimation, 200 SPS sequence obtained after band limited interpolation of El Centro, Taft and Uttarkashi accelerograms were decimated to 50 SPS sequence by two methods. Response spectra for the sequence of 50 SPS obtained by above methods were determined. It was found that response spectra of the sequences obtained by both methods match quite well and the difference was less than 5% at all the periods for above earthquakes. Figure 4 gives such comparison for El Centro motion. For other motions the matching is similar. These results prove that decimation through dropping of samples can be used quite safely.

TRANSDUCER CORRECTION

Transducer correction is applied to obtain the actual ground motion from the record which is really the response of the single degree of freedom transducer. This correction can be applied in time domain or in frequency domain. In time domain, most authors use central difference method to find solution of

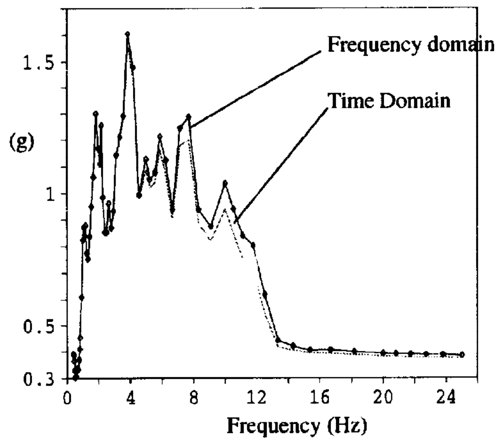

Fig. 4. Spectra of El Centro Motion Decimated from 200 SPS to 50 SPS

equation of motion of the single degree of freedom transducer. It has been reported by Shyam Sunder and Connor (1982) that transducer correction done through central difference scheme give erroneous results at frequencies more than one third of the Nyquist frequency. Such results have also been reported by some other authors. In frequency domain, the transducer correction is done by dividing the Fourier transform of the record with transfer function of the transducer and then taking inverse Fourier transform. To compare the two methods of transducer correction, linearly interpolated sequence at 200 SPS for El Centro, Taft and Uttarkashi motion was taken as input. Transducer corrected history was then determined through time domain as well as in frequency domain methods. Also, these input sequences were decimated to 50 SPS and then transducer correction was applied through time domain as well as frequency domain methods. Response spectra for all the four transducer corrected histories and for three earthquakes were determined. It was found that response spectra determined from transducer corrected sequences of 200 SPS for both frequency and time domain match quite well. However, response spectra determined from transducer corrected sequence of 50 SPS for frequency domain gives small variation in high frequency and gives substantially different results when 50 SPS sequence is processed in time domain. Figure 5 give results for the four cases for El Centro motion. Similar results are obtained for other earthquakes. These results show that transducer correction done in frequency domain is more reliable than that in time domain.

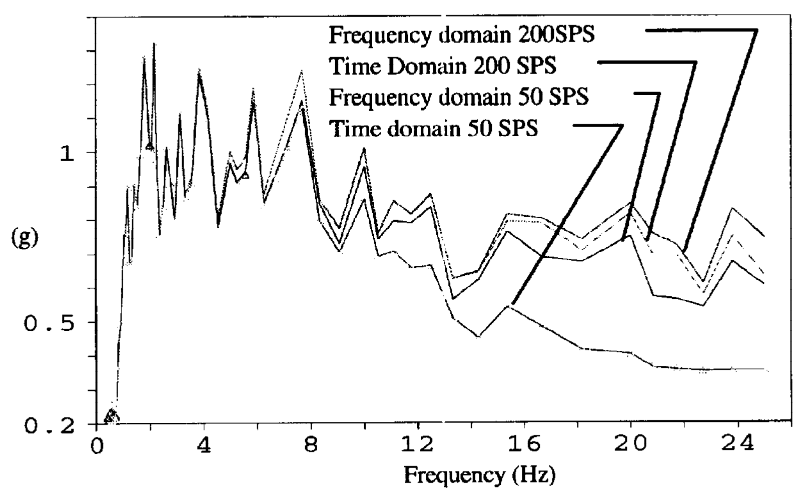

Fig. 5. Spectra of El Centro Motion after Effecting Transducer Correction

BAND PASS FILTER

During recording as well as during the process of digitization, low frequency and high frequency noise creeps into the record. This is removed through a band pass filter. Low frequency noise in the uncorrected sequence is studied in frequency domain to determine the lower side of the cut off frequency of the band pass filter. Upper side of the cut off frequency of band pass filter is generally taken as 25 Hz. Different authors have used different type of filters to perform this work. Ormsby filter in time domain, Butterworth filter in time domain, Butterworth filter in frequency domain and half cosine filter have been used by different authors. In this part of the work, linearly interpolated sequence at 50 SPS of earthquake motions are taken as input and are band pass filtered by above methods. The cut off frequency in each of the filter was taken as 0.01 Hz and 23 Hz. The roll off in Ormsby and half cosine filter was taken as 0.02 Hz and 2 Hz at lower cut off and upper cut off respectively. Response spectra (2% damping) of band passed sequences for the four cases was determined. It has been found that response spectra for all the four cases match quite well which shows that type of filter used is not of much consequence. Figure 6 shows these results for El Centro motion.

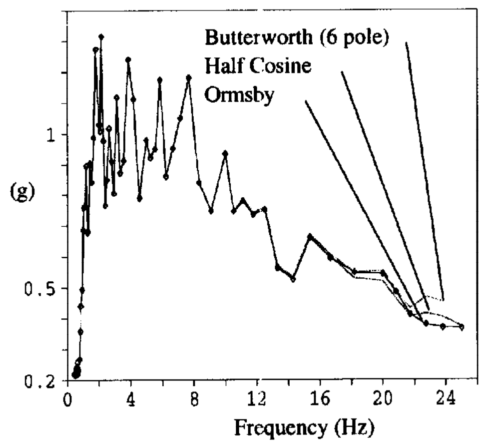

Fig. 6. Comparison of Spectra using Different Filters

INTERPOLATION OF EQUALLY SPACED DATA

The corrected sequence so obtained may not be of desired sampling rate and therefore interpolation of this sequence is often done to get the desired sampling rate. This interpolation is sometimes done by the person who processes the data and sometimes by users of the data. Conventionally linear interpolation is done to increase sampling rate. Kumar *et al.* (1995, 1994) and Basu *et al.* (1992) have shown that linear interpolation distorts signal and have suggested to use band limited interpolation by first zero packing the data and then low pass filtering with cut off frequency equal to Nyquist frequency of original sequence. This method of interpolation preserves frequency contents of original sequence and is termed as band limited interpolation. Linearly interpolated sequences of El Centro, Taft and Uttarkashi at 50 SPS are taken as input . These are linearly as well as band limited interpolated to get a sampling rate of 200 SPS. Comparison of response spectra (2% damping) for two methods of interpolation show that linearly interpolated sequence give substantially different spectra for all the three earthquakes. Figures 7-9 show the comparison of spectra for El Centro, Taft and Uttarkashi motions.

CONCLUSIONS

During the course of this work as well as earlier work in this field, it has been found that most analysts and researchers treat accelerogram as analog (continuous) signal. Whereas, an actual earthquake is surely a continuous process but the fact remains that the accelerogram available is digital in nature and there is no

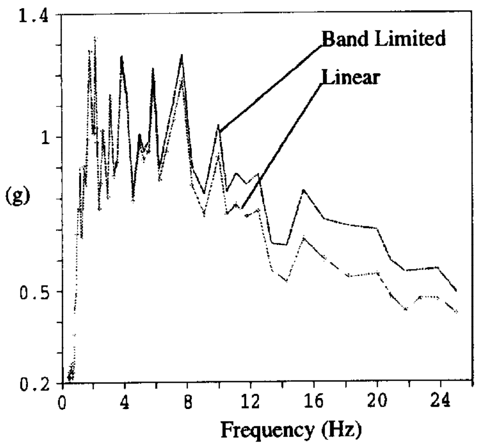

Fig. 7. Comparison of Spectra of El Centro Uniform Sequence Interpolated Linearly and by Band Limited Method

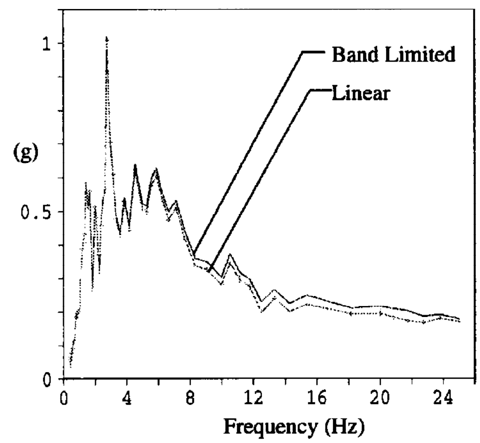

Fig. 8. Comparison of Spectra of Taft Uniform Sequence Interpolated Linearly and by Band Limited Method

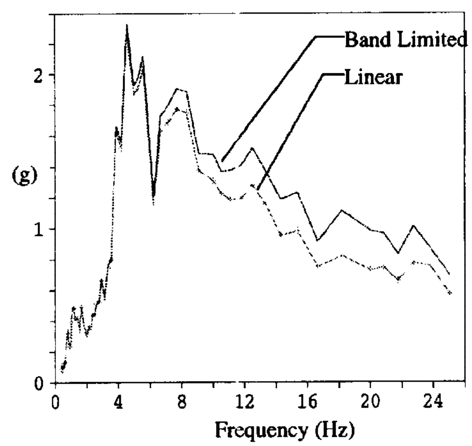

Fig. 9. Comparison of Spectra of Uttarkashi Uniform Sequence Interpolated Linearly and by Band Limited Method

alternative other than to work within the limitation and properties of digital data which is always band limited. The philosophy of linear interpolation emerges from the imagination that accelerogram is a continuous signal and therefore acceleration in between the two samples can be found through linear interpolation. But such interpolation contradict the basics of digital signal processing as it generates spurious signal in frequencies which were not defined in the original sequence, at the cost of frequencies existing in the original sequence. In other words, linear interpolation corrupts the accelerogram if it is viewed in the frequency domain. It is, therefore, important that process of interpolation should be such that the frequency content of the data remain unchanged after the interpolation. Band limited interpolation scheme of uniformly spaced and non uniformly spaced sequences satisfies this requirement. The conclusions derived from this work can be summed up as follows :

1. Linear interpolation of non uniformly spaced samples to get uniformly spaced samples gives substantially different results in comparison to band limited interpolation. Methods of recovering signal from non uniformly spaced samples is a recent development in the field of digital signal processing. However, this development has brought out drawbacks of strong motion data that has been used over the years in the field of earthquake engineering.

2. Type of decimation used and type of filter used in processing of accelerogram is not important.

3. Instrument correction if done in time domain should use the sequence at a sampling rate not lower than 200 SPS.

4. Increase of sampling rate of the corrected sequence through linear interpolation distorts data and band limited interpolation should be used.

REFERENCES

Basu, S., Pankaj and Kumar, A. (1992). On the Importance of Band Limited Excitation in Direct Integration Analysis of Structures; *Proceedings Tenth World Conference on Earthquake Engineering, Madrid, Spain, July 1992;* 3779-3785

Erdik, M. and Kubin, J. (1984). A Procedure for the Accelerogram Processing. *Proceedings Eighth World Conference on Earthquake Engineering, San Francisco, USA,* **Vol. II**, 135--139.

Khemici, O. and Chiang, W.L. (1984). Frequency Domain Corrections of Earthquake Accelerograms with Experimental Verification. *Proceedings Eighth World Conference on Earthquake Engineering, San Francisco, USA,* **Vol. II**,.103--110.

Kumar, A.(1993). New Schemes for Processing Accelerograms. *Ph.D. Thesis; Department of Earthquake Engineering, University of Roorkee, Roorkee;* Feb. 1993.

Kumar, A., Basu, S. and Chandra, B.(1992). The Effect of Band Limited Interpolation of Non uniform Samples on Records of Analog Accelerographs; *Bulletin Indian Society of Earthquake Technology;* **Vol. 29, No. 4,** 53-67.

Kumar, A, Basu, S. and Chandra, B. (1995). BLACS-- A New Correction Scheme of Analog Accelerograms Part 1 and Part 2. *Bulletin Indian Society of Earthquake Technology,* **Vol 32, No. 2**, pp33-71

Kumar, A., Pankaj and Basu, S. (1994) Effect of Linear Interpolation on Response Spectra. *Proceedings Tenth Symposium on Earthquake Engineering, Roorkee, Nov. 1994.* 869-878.

Lee, V.W. and Trifunac, M.D. (1979). Automatic Digitization and Processing of Strong Motion Accelerograms. *Report of Department of Civil Engineering, University of Southern California, U.S.A, Report no. 79--15,* **Vol. I and II.**

Performance of Strong Motion Instruments in Garhwal (UP) Earthquake of Oct. 20, 1991; Vol. II: Analysis of Records obtained on Strong Motion Accelerographs (RESA V). *Report of Department of Earthquake Engineering, University of Roorkee, Roorkee, India, Report no. EQ 93-07.*

Shyam Sunder, S. and Connor, J.J. (1982). A New Standard Processing Scheme for Strong Motion Earthquake Signals. *Bulletin of Seismological Society of America,* **Vol. 72, No. 2**,.643--661.

Strong Motion Earthquake Accelerograms; Vol.I Uncorrected Accelerograms (1970). Report of Earthquake Engineering Research Laboratory. California Institute of Technology, Report no. EERL 70--20, Vol. I, Part A.