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# NOISE CHARACTERISTICS OF A STRONG MOTION ACCELEROGRAPH

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**Abstract**

In India, RESA V accelerographs developed at the Department of Earthquake Engineering, University of Roorkee have been installed at more than 100 sites. However, a detailed study of the noise characteristics of RESA V had not been done. This paper presents noise characteristics of RESA V which has been determined by digitizing straight line traces of 10, 20, and 30 second duration. The digitizing is done by three operators who digitized each of the trace three times on a semi automatic type digitizer. The digitized data is converted into uncorrected accelerogram. Velocity spectra and Fourier spectra of uncorrected accelerogram of the noise is determined and an illutrative example is given to show the use of these spectra in choosing cut off frequencies for correction of a recorded earthquake accelerogram. The uncorrected accelerogram of the noise is corrected using Trifunac's scheme and statistical estimate of quantum of noise present in corrected acceleration, velocity and displacement data is presented.

## BRIEF DESCRIPTION OF RESA V

The working principle of RESA V is similar to other commonly used analog accelerographs like SMA 1. This instrument has mechanical starting pendulums of natural period of about 0.8 second and damping of around 30% of critical. The instrument is triggered when any one of these pendulums makes contact with a contact screw. The gap between pendulums and contact screws is so adjusted as to get contact at approximately 30 gals. The three accelerometers of RESA V use torsional pendulums and have a natural frequency ranging from 22 to 25 *Hz* and a damping of around 60% to 65% of critical. Each accelerometer pendulum has a concave mirror fixed to it which reflects the image of filament of the light source as a sharp spot on the moving photographic paper with the help of suitable optics. The deflections of the mirror of pendulums are amplified using an optical lever and have a sensitivity of about 30 *mm* for unit acceleration due to gravity ($g$). The record of the instrument is obtained on 22.5 *cm* wide photographic paper which moves inside the camera at a speed of 2 *cm/sec*. The time mark of the instrument provides quarter second OFF and quarter ON spots on the moving photographic paper. The instrument operates for about 10 *seconds* after the last contact of any one of the triggering pendulum. The instrument is controlled electronically and the entire circuit is in a $14cm \times 9cm$ PCB which is mounted on a control panel. The performance of this instrument has been studied using shaking table in comparison to an American RFT-250 accelerograph with almost similar results (Srivastava and Kumar (1980)). This instrument has given useful strong motion data in recent past and several of them triggered in North-East India earthquake of August 1988 (Report no. EQ 89–09), Bihar-Nepal earthquake of August 1988 (Report no. EQ 88–16) and the Garhwal Earthquake of October 1991 (Report no. EQ 92–01).

## NOISE CHARACTERISTICS AND ITS CLASSIFICATION

It is well known that during recording and digitization of records of analog accelerographs like RESA V, noise creeps in due to a number of reasons (Trifunac et al. 1973). Three specific reasons that necessiate detailed analysis of noise are as follows:

1. Choice of frequency band for the processing of the record which should ideally be noise free and in actual practice with an acceptable signal to noise ratio. This implies that for an acceptable signal to noise ratio, suitable cutoff frequencies of the band pass filter for processing the record can be estimated by comparing the noise characteristics with that of characteristics of the uncorrected accelerogram.

2. Estimatation of the level of error in time domain which is present in the corrected accelerogram. This is done to apprise the users of the data about the estimate of inherent error that is present even in corrected data and in derived velocity and displacement.

3. Understanding of the complete process of recording, digitization and correction schemes. This, not only provides confidence in our processing methods but also gives an insight that helps in formulating specifications for use in the design of a better instrumentation system for the future.

It may be mentioned here that noise characteristics so determined, consist of several uncertainties due to characteristics of each instrument, thickness of the trace, judgement of operator performing the digitization, level of signal and resolution of the digitizer. It may also be mentioned that it will be impractical to study the noise characteristics for each installed instrument and determine signal to noise ratio for each record. Therefore, the parameters determined by such a study *viz.* cutoff frequencies of band pass filter for a required signal to noise ratio and level of error in the corrected data are not the exact and absolute values but can at best be considered as an estimate.

Iai (1988) classified noise according to the nature of its time history which can be periodic or random or of limited duration.

In case the noise is assumed to be periodic then the Fourier transform of the noise will be proportional to the duration of the record ($T$) and the Fourier spectrum will be independent of duration. This assumption is not applicable in this case where the noise cannot be treated as a periodic function.

If the noise is assumed to be a random infinite sequence then Fourier transform of the noise for a duration of the record $T$ will be proportional to square root of the duration ($\sqrt{T}$). Iai *et al.* (1980) and Iai *at al.* (1988) consider noise in this fashion. However, the recorded noise is not the background noise which can be assumed to be an infinite sequence but it is instrumental noise which creeps in due to various physical reasons during the process of recording and digitization and has a finite duration equal to that of the record.

In this study the noise is assumed to be of finite duration and therefore the Fourier transformation of this noise will be independent of $T$ and Fourier spectrum will be inversely proportional to the duration. For such a case Fourier transformation of the noise will be approximately same as the velocity response spectra for zero damping or for very small damping. Trifunac (1976,1977) and Trifunac and Lee (1978) also treat noise in this fashion.

## METHODOLOGY AND RESULTS

Experiments were conducted for determining the noise characteristics on a RESA V accelerograph which has specifications similar to most other instruments installed at various locations in India. Table 1 gives the calibration constants of the instrument used for the purpose. This instrument was made to trigger several times in a peaceful environment and records for 10, 20 and 30 *seconds* trigger were obtained. One of the accelerometer trace of each of these records were digitized by three operators. Each operator digitized each trace three times. Thus, each record (10, 20 sec and 30 seconds trigger) was digitized nine times. The digitization was performed on a semi-automatic digitizing table which had a resolution of 1/1000 of an inch.

Table 1: Calibration Constants of RESA V

| Natural frequency ($Hz$) | % of critical damping | Tilt sensitivity ($mm/g$) | Time for 20 ON of time mark (*second*) |
|---|---|---|---|
| 22.5 | 63.6 | 29.8 | 19 |

Using the calibration constants of the instrument, all the 27 digitized records (files) were converted into unequally sampled uncorrected accelerograms with base line being taken as the least square line of the record. A linear interpolation was done to get 27 uncorrected accelerograms at an equal sample interval of 0.005 *second*. Fourier transformation spectra and velocity response spectra for zero damping of all the 27 files were determined. The average Fourier transformation spectra of 9 files each of 10,20,30 *seconds* records and average Fourier transformation spectra of all the 27 files are plotted one over the other for frequencies upto 25 *Hz* and are shown in Fig. 1. Similarily 3 sets of velocity response spectra for zero percent damping was determined using algorithm of Nigam and Jennings (1968,1969). Figure 2 shows above 3 sets of velocity response spectra alongwith average velocity response spectrum of all the 27 files.

The velocity response spectra for zero damping and the Fourier transformation spectra should be almost same for a particular excitation and Velocity response spectra should be above Fourier response spectra at each point (Hudson 1970). However, this is not getting reflected in Figs. 1 and 2. This is due to the fact that averaging of large number of files have been done to obtain these figures. However, a doubt gets created about the validity of the softwares used for determining velocity response spectra and Fourier transformation spectra. For the determination of velocity response spectra, the software developed by Nigam and Jennings (1968) was used, which is well established and commonly used software. For the computation of the Fourier transformation spectra, a software comprising fast Fourier transform using Radix-2 algorithm (with decimation in frequency) is used (Burrus and Park 1985). To compare the results from the two programs, first of all Fourier transformation spectra of an earthquake motion was determined. The velocity response spectra for zero percent damping for the same earthquake was determined for 50 frequencies between 1 *Hz* and 2.2 *Hz*. These 50 frequencies were the same as the bin frequencies of Fourier transformation spectra. The two spectra were plotted one over the other as shown in Fig. 3. The results are as expected and it can be seen that the nature of the two spectra is almost the same and velocity response spectra is above Fourier transformation spectra at all the frequency points (Hudson 1970). To demonstrate the use of Fourier transformation spectrum of noise in selecting the appropriate cut off frquency, a record obtained at Uttarkashi on RESA V during Garhwal earthquake of October 20, 1991 was used. Fourier transformation spectrum of uncorrected accelerogram of earthquake record which was interpolated at .005 *second* was obtained. This spectrum was plotted alongwith average Fourier transformation spectrum of the noise upto a frequency of 25 *Hz* as shown in Fig. 4. The signal to noise ratio of this record was determined by dividing the two spectra of Fig. 4 at each frequency point, keeping the bin frequency of two spectra same. Figure 5 gives a curve of signal to noise ratio at each frequency point. This curve was smoothened with a running mean filter. Figure 6 show smoothened signal to noise ratio of the record. If a signal to noise ratio of 10 is required then a cut off frequency of 0.5 *Hz* is essential. For lowpass filter a cutoff frequency of 25 *Hz* is ideal because the level of signal at higher frequencies is very small as can be seen from Fig. 4.

To estimate the noise in time domain, the uncorrected time histories of the noise were processed by the scheme of Lee and Trifunac (1979) with a cutoff frequency for high pass filter as 0.1 *Hz* with a roll-off of 0.02 *Hz* and a cutoff frequency for low pass filter as 25 *Hz* with a roll-off of 2 *Hz*. The maximum acceleration of the noise history of the 27 files had an average of 5.791 *gals* with a standard deviation of 2.106 *gals*. The maximum derived velocity of the noise history of the 27 files had an average of 2.043 *cm/sec* and

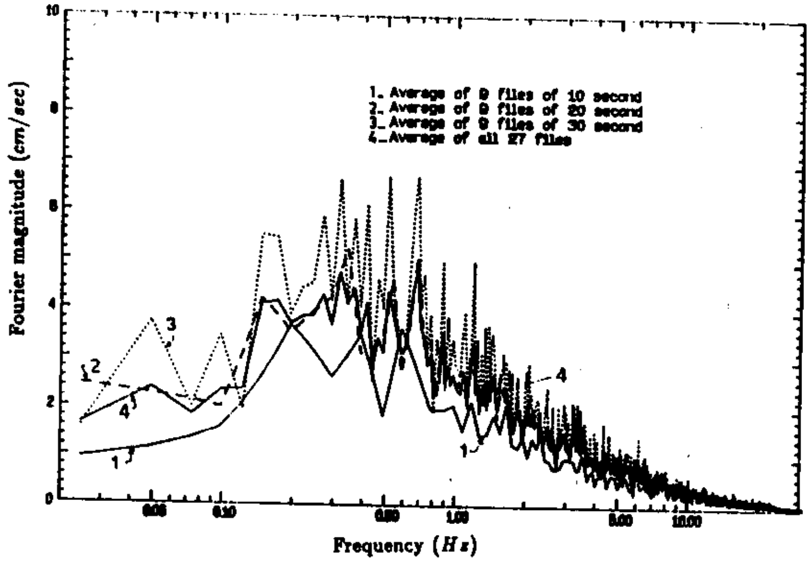


**Figure 1:** Average Fourier magnitude of noise of RESA V

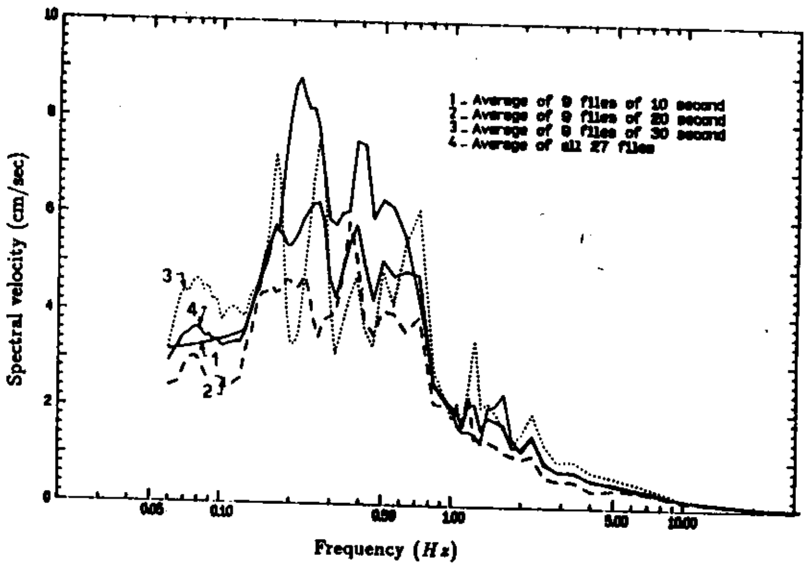


**Figure 2:** Average velocity response spectra of noise

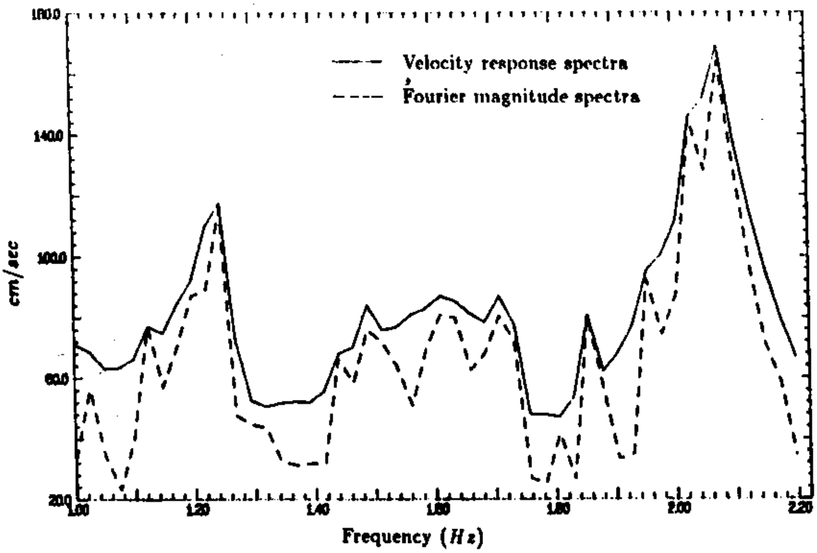


Figure 3: Comparison of velocity response spectra and Fourier magnitude spectra for validation of computer programs.

a standard deviation of 0.925 *cm/sec*. The maximum derived displacement of the noise history of the 27 files had an average of 2.48 *cm* and a standard deviation of 1.46 *cm*. Table 2 summerizes the above results. Figure 7 shows one of the noise acceleration, velocity and displacement history.

## CONCLUSIONS

Study of noise characteristics of RESA V is done in this part of the work. The following are the conclusions of this work:

1. The noise in an accelerograph is of finite duration. This is amply demonstrated in Fig. 1 where average Fourier Transformation amplitude of 10, 20 and 30 *seconds* records are plotted one over the other and which shows that Fourier Transformation is independent of duration $T$.

2. The level of noise in low as well as in high frequency range in the system (RESA V and digitizer used) is more than the noise reported by American systems. This is attributed to the trace thickness of RESA V which is substantially more than American accelerographs like SMA 1 and to some extent characteristics of the digitizer.

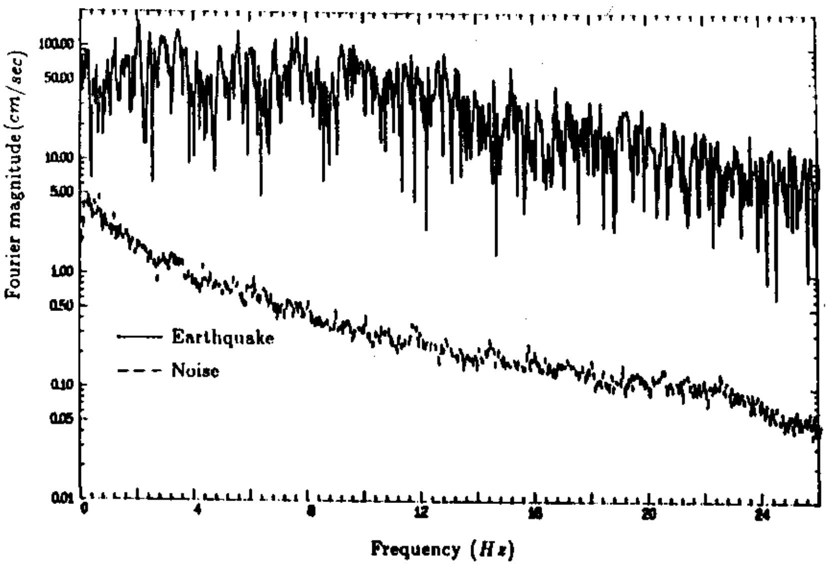


**Figure 4: Fourier magnitude spectra of uncorrected Uttarkashi accelerogram and noise.**

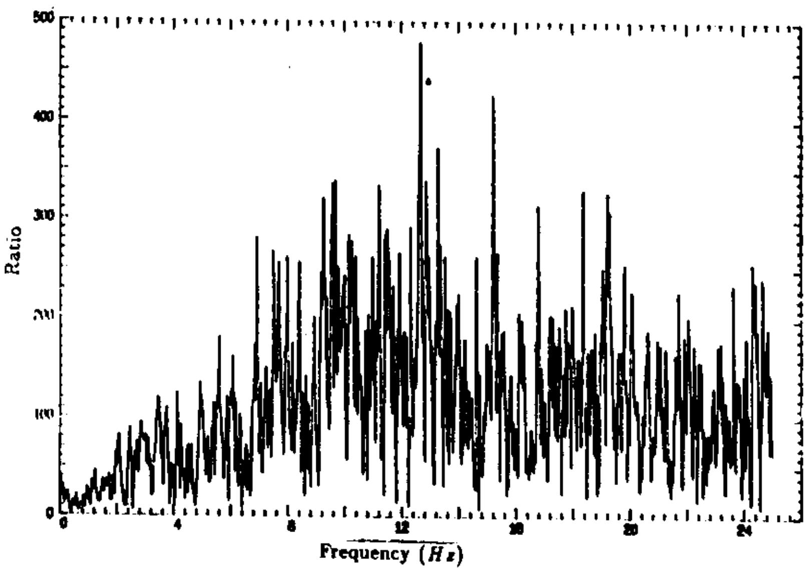


**Figure 5: Earthquake signal (Uttarkashi accelerogram) to noise ratio**

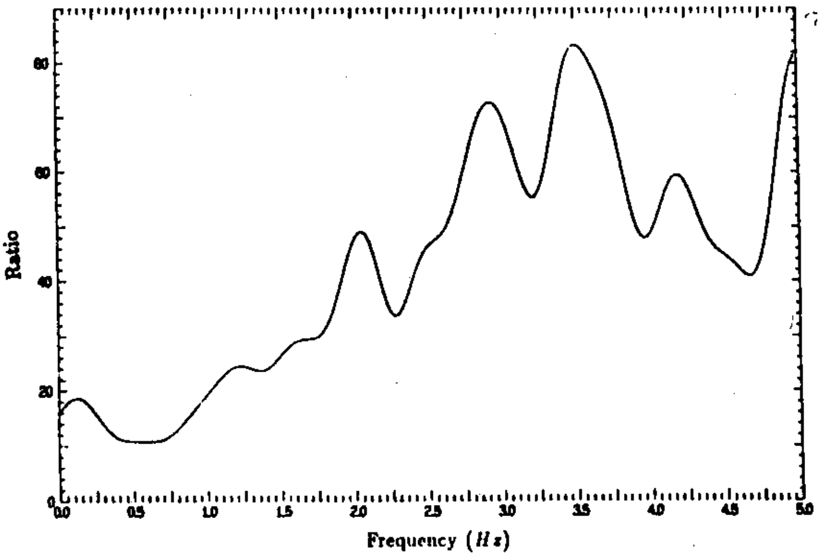


Figure 6: Smoothened earthquake signal to noise ratio (for frequencies upto 5 $Hz$)

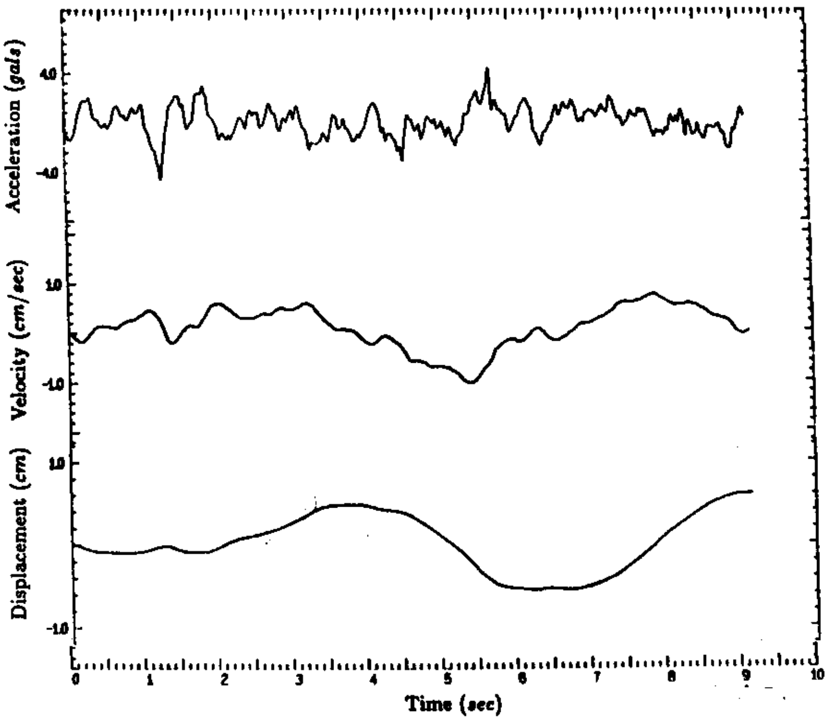


Figure 7: A typical corrected noise acceleration, velocity and displacement history

Table 2: Noise of RESA V

| Duration *sec* | Acceleration *gals* | | Velocity *cm/sec* | | Displacement *cm* | |
|---|---|---|---|---|---|---|
| | Mean | $\sigma$ | Mean | $\sigma$ | Mean | $\sigma$ |
| 10 | 5.801 | 2.126 | 1.758 | 0.843 | 1.310 | 0.621 |
| 20 | 5.812 | 2.118 | 1.938 | 0.842 | 3.015 | 1.450 |
| 30 | 5.760 | 2.070 | 2.353 | 1.017 | 3.124 | 1.361 |
| Overall | 5.791 | 2.106 | 2.043 | 0.925 | 2.480 | 1.460 |

3. Due to the above reasons values of average noise in time domain for acceleration, velocity and displacement of RESA V is more than their American counterparts. Perhaps, the optics of RESA V needs improvements and a more accurate digitizing table is required.

4. A method has been shown to choose cutoff frequency for records of RESA V which is based on signal to noise ratio of earthquake signal and noise. This ratio has been found in each bin frequency of Fourier transformation amplitude of uncorrected accelerogram and that of noise. However, such methods for choosing cut off frequencies require judgement which can vary from person to person.

## REFERENCES


1. **Burrus, C.S.** and **Park, T.W.** (1985) —DFT/FFT and Convolution Algorithms. *John Wiley, New York.*

2. **Hudson, D.E.** (1970) —Ground Motion Measurements. *Chapter 6 of Earthquake Engineering ; Coordinating Editor R.L. Wiegel, Prentice Hall, Inc. Englewood Cliffs, N.J.*

3. **Iai, S.** (1988) —State of the Art: Processing of Analogue Strong Motion Seismic Record. *Proceedings of the Second Workshop on Processing of Seismic Strong Motion Records, Tokyo, Japan,*Vol. I, pp.1–9.

4. **Iai, S., Kurata, E., Tsuchida, H.** and **Hayashi, S.** (1980) —Integration of Strong Motion Accelerograms. *Proceedings of the Tenth Joint Panel Conference of the U.S.-Japan Cooperative Programme in Natural Resource, Wind and Seismic Effects,*H.S. Lew Ed., NBS, Special Publication 560, U.S. Department of Commerce/Nation Bureau of Standards, pp7–1 to 7–16.

5. **Iai, S., Tsuchida, H., Kurata, E.** and **Noda, S.** (1988) —Processing of Strong Motion Records by Port and Harbor Research Institute, Japan. *Proceed-*

*ings of the Second Workshop on Processing of Seismic Strong Motion Records, Tokyo, Japan*, Vol.1, pp.51–67.

6. **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.

7. **Nigam, N.C. and Jennings, P.C. (1968)** —Digital Calculation of Response Spectra from Strong Motion Earthquake Records. *Report of Earthquake Engineering Research Laboratory, California Institute of Technology, June, 1968.*

8. **Nigam, N.C. and Jennings, P.C. (1969)** —Calculation of Response Spectra from Strong Motion Earthquake Records. *Bulletin of the Seismological Society of America*, Vol. 59, No. 2, pp909–922.

9. **Srivastava, H.N. and Kumar, A. (1980)** —Performance test of accelerograph (RESA V) designed and developed by Department of Earthquake Engineering, University of Roorkee, Roorkee. *Report of Department of Earthquake Engineering, University of Roorkee prepared for INSMIN project.*

10. **Trifunac, M.D. (1976)** —Preliminary Emperical Model for Scaling Fourier Amplitude Spectra of Strong Ground Motion Acceleration in Terms of Earthquake Magnitude, Source to Station Distance, and Recording Site Conditions. *Bulletin of the Seismological Society of America*, Vol. 66, No. 4, pp1343–1373.

11. **Trifunac, M.D. (1977)** —Uniformly Processed Strong Earthquake Ground Acceleration in the Western United States of America for the Period from 1933–1971: Pseudo Relative Velocity Spectra and Processing Noise. *Report University of Southern California*, Report no. CE 77–04.

12. **Trifunac, M.D. and Lee, V.W. (1978)** —Uniformly Processed Strong Earthquake Ground Acceleration in the Western United States of America for the Period from 1933–1977: Corrected Acceleration, Velocity and Diaplacement Curves. *Report University of Southern California*, Report no. CE 78–01.

13. **Trifunac, M.D., Udwadia, F.E. and Brady, A.G. (1973)** —Analysis of Errors in Digitized Strong Motion Accelerograms. *Bulletin of Seismological Society of America*, Vol. 63 No. 1.

14. —(1988) Performance of Strong Motion Instruments During Bihar–Nepal India Earthquake of August 21, 1988. *Report of Department of Earthquake Engineering, University of Roorkee*, Report no. EQ 88–16.

15. —(1989) Performance of Strong Motion Instruments During North–East India Earthquake of August 6, 1988. *Report of Department of Earthquake Engineering, University of Roorkee*, Report no. EQ 89–09, June, 1989.

16. —(1992)Preliminary Report on Performance of Strong Motion Instruments in Garhwal (U.P.) Earthquake of Oct. 20, 1991. *Report of Department of Earthquake Engineering, University of Roorkee*, **Report no. EQ 92–01, January, 1992.**