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Correction of data obtained from digital accelerographs

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ABSTRACT: It is well recognised that data recorded from digital accelerographs have substantially smaller noise to signal ratio in the frequency range of recording as compared to analog accelerogarphs. In this paper the noise history is determined by visually identifying the start of event in the pre event portion of the accelerogram and then taking the remaining pre event record as instrument noise. Fourier spectra of this noise is used to get Fourier spectra of the signal which on inversion would lead to corrected accelerogram. To examine the efficacy of this procedure, the digital accelerograph was made to record an earthquake motion generated by a computer controlled shake table. The motion prescribed was such that it had zero displacement at the end of motion. The record obtained from digital accelerograph was corrected with the help of Fourier spectra of its noise. The corrected accelerogram was then integrated to obtain velocity and displacement histories. The results showed almost zero values of velocity and displacements at the end of motion which proves the effectiveness of the proposed correction scheme.

1 INTRODUCTION

Data recorded from digital accelerographs have substantially smaller noise to signal ratio in the frequency range of recording as compared to analog accelerographs. This is due to the fact that a) digital accelerographs have no moving parts as in analog accelerographs, b) data of digital accelerographs are free from human errors assosiated with digitization of records of analog accelerographs and c) sensors of digital accelerographs (mostly FBAs) are more accurate, have higher natural frequency and larger dynamic range. Due to these very reasons it may be assumed that each digital accelerograph have unique noise characteristics of its own which we should be able to determine. This paper briefly describes a digital accelerograph developed at Department of Earthquake Engineering, University of Roorkee, India and suggests a procedure which uses untriggered portion of the pre event data to determine the noise characteristics of digital accelerograph and suggests a frequency domain method to use this noise characteristics to obtain the corrected accelerogram. To examine this correction procedure, the digital accelerograph was made to record a prescribed earthquake time history generated on a computer controlled shake table. The table movement prescribed was such that it had zero displacement at the end of motion. The record obtained from digital accelerograph was corrected with the help of Fourier spectra of its noise. The corrected accelerogram was then integrated to get velocity and displacement histories. The results showed almost zero values of velocity and displacement at the end of motion.

2 THE DIGITAL ACCELEROGRAPH

The digital accelerograph developed at Department of Earthquake Engineering, University of Roorkee (Kumar et al. 1990 & EQ. Report 1990) is based on 8085 microprocessor and data are obtained on solid state memory. The instrument also records pre event data and absolute time of starting of the event. A triaxial force balance accelerometer is used as transducer. The output of the transducer is fed to a signal conditioner which amplifies the output and removes frequencies above 33 Hz. The output of signal conditioner is fed to 12 bit analog to digital converter (ADC) which works in tandem with microprocessor and converts the analog signal into digital values at the desired sampling rate. Each digital value is then sent to the accumulator of the microprocessor which compares the value with the given threshold acceleration and determines whether the event has occured or not. In case the event has not occured, the digital data is fed to a set of memory locations (referred as ring storage). The number of memory locations in the ring storage are sampling rate multiplied by time for which pre event data is required. The digital values of the output are stored in this ring storage as long as the event does not occur. The moment the earthquake comes and the threshold ground acceleration exceeds the given value, the microprocessor starts sending the digital values of the output to open ended memory locations. The microprocessor also records the absolute time (day, day of week,month,hours,minute,second,mseconds) of occurrence of the earthquake in the flag of the software. The flag also stores other important informations of the event like starting address, end address, jump address of pre event etc. The detailed specifications of the instrument are given in Table-I. The data so recorded on solid state memory is retrieved on a floppy through a IBM compatible PC.

3 TRANSFORMATIONS & NOISE IN DIGITAL ACCELEROGRAPH

Although the noise to signal ratio in the data recorded from digital accelerographs is far less than that in analog accelerographs (Iwan et. al. 1985), yet, the record of the digital accelerograph does get transformed at various stages and in the process noise does creep in.

The first transformation takes place in the accelerometer where acceleration is converted into equivalent voltage. Closed form solution in frequency domain for transfer function of FBA are available (Amini and Trifunac 1985). This transfer function can be used to get the acceleration from the recorded voltage output through deconvolution.

Another signal transformation takes place at the signal conditioner. Here the the anti aliasing filter removes high frequencies and the voltage signal is amplified to a required range. A four pole Butterworth filter is used with a cutoff frequency of 33 Hz in the above mentioned digital accelerograph.

Although anti aliasing filter is an essential requirement for any digital recording system but the fact remains that most of these analog filters like Butterworth etc produce nonlinear phase shift. Whereas in the opinion of the authors these nonlinear phase shifts should not be of much consequence but earthquake engineers have some objections for this (Lee 1984). One of the method of getting rid of this nonlinear phase shift is to design a 4 pole digital Butterworth filter and perform the filtering operation with inverted time history and then invert the output again. This means that operation for $|H(jw)|$ has already taken place at analog stage and operation for $|H(-jw)|$ is performed for the recorded digital data to obtain zero phase shift.

In addition to above transformations, the system continuously record some noise which is of the order of 5 to 6 least significant bits (lsb). It is this noise which has been examined in this paper and a procedure is suggested to remove this noise and obtain the corrected accelerogram.

4 SUGGESTED PROCEDURE FOR REMOVAL OF NOISE

One of the way of determining noise for each channel of a digital accelerograph is by triggering the instrument in a peaceful environment. However, this method is not very convincing due to the fact that it will be hard to believe that the noise characteristics of the instrument will not change in course of time. It is for this reason that a method has been suggested in which the untriggered portion of the pre event has been used to identify the characteristics of the noise and the same is used to extract the signal. The details of the procedure are as given below.

1. The pre event portion of the time history is studied carefully and start of the event is identified by zooming the record.

2. The initial part of pre event and upto the start of event is taken as samples of noise in the instrument. These data of the noise are assumed to be ergodic. The raw data is assumed to be corrupted by the background noise present in the system. The noise is also assumed to be periodic with the finite numbers of samples recorded during a particular earthquake. From the sample of record with aforesaid assumed periodicity, a noise history is created for the actual duration of earthquake.

3. From the Fourier components of uncorrected accelerograms, the corresponding noise components at various frequency bins are subtracted.

4. The resulting Fourier components are low pass filtered with a cut off frequency of 33 Hz by performing the convolution corresponding to $|H(jw)|^2$ of 30 pole Butterworth filter.

5. These data are inverted back to get the corrected accelerogram in the time domain.

5 SHAKE TABLE TEST

To check the effectiveness of the above correction

Table 1: SPECIFICATIONS OF DIGITAL ACCELEROGRAPH

- Triaxial force balance accelerometer (Columbia make SA-327TX)
- Full scale range: +/- 2g (other ranges available)
- Damping: 0.70 of critical
- Resolution: 12 bits
- Signal Conditioner: Four pole Butterworth filter with variable gain
- Recording Bandwidth: 0.05 to 33 Hz.
- Processor: INTEL 8085
- Sample Rate: Menu selectable upto 200 SPS
- Trigger Mode: Signal derived from accelerometer
- Trigger Level: Menu selectable upto 0.03g
- Pre Event Memory: Menu selectable upto 10 seconds
- Post Event Memory: Menu selectable upto 20 seconds
- End of Event Level: Menu selectable upto 0.03g
- Memory: CMOS Ram (512 KByte)
- Battery Backup: Provided for memory card
- Recording Time: 15 minutes at 100 SPS for 3 channels
- Internal Clock: INTEL 5832 calender chip
- Data Retrieval: On IBM compatible PC
- Battery: 2 no. 12 volt 24 AH sealed lead acid battery
- Battery Charger: 220 Volts
- Weight: Approx. 15 Kg.
- Size: 370 X 370 X 200 mm

scheme, the digital accelerograph was made to record the motion of a biaxial computer controlled shake table. The shake table was excited by a prescribed time history. The shake table motion had a duration of 10.24 seconds and had zero displacement at the end of the motion. The digital accelerograph was set with the following parameters:

$$\begin{aligned} \text{Sampling rate} &= 100\ SPS \\ \text{Pre event time} &= 5\ sec \\ \text{Trigger level} &= 0.03g \\ \text{Post event time} &= 5\ sec \\ \text{End of event level} &= 0.03g \end{aligned}$$

The raw time history as obtained from the above test is shown in Figure 1. It can be seen from this figure that pre event portion has a thick line which really is a high frequency noise which is being dealt with in this paper. This figure was studied more closely by zooming it, at around the place where the event has started and the instant of the exact start of the event was picked up. In this case, it was seen that the first 490 samples were the pre event portion. The noise history was obtained by repeating the sequence of first 490 samples of pre event to get the same number of samples as are there in the record. Figure 2 shows comparison of Fourier spectra of raw earthquake data and that of noise. The correction scheme as outlined in the earlier section was used to get the corrected data. Fig. 3 shows the corrected accelerogram of the entire time history. Although for all practical purposes the noise in the pre event of corrected time history was zero, yet, very small numerical values in the pre event portion created computational problems during integration to get velocity and displacement. Due to this reason 1024 samples corresponding to 10.24 sec duration of shake table motion starting from 491 sample was extracted as the actual record. This record was corrected with the same correction scheme and it yielded good results. This gave a displacement of -0.017 cm and a velocity of -0.017 cm/sec at the end of motion which for all practical purposes can be assumed to be zero. Figures 4 to 6 show corrected time histories of acceleration, velocity and displacement for 10.24 sec motion.

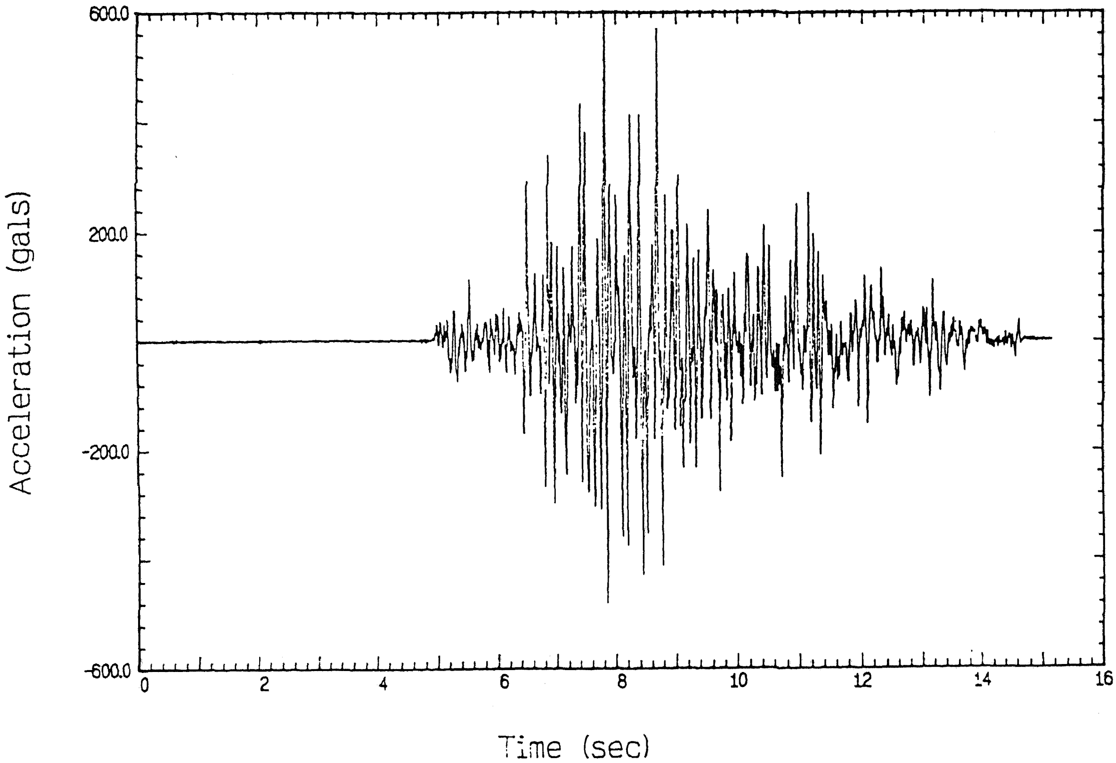

Figure 1: Raw time history of shake table motion

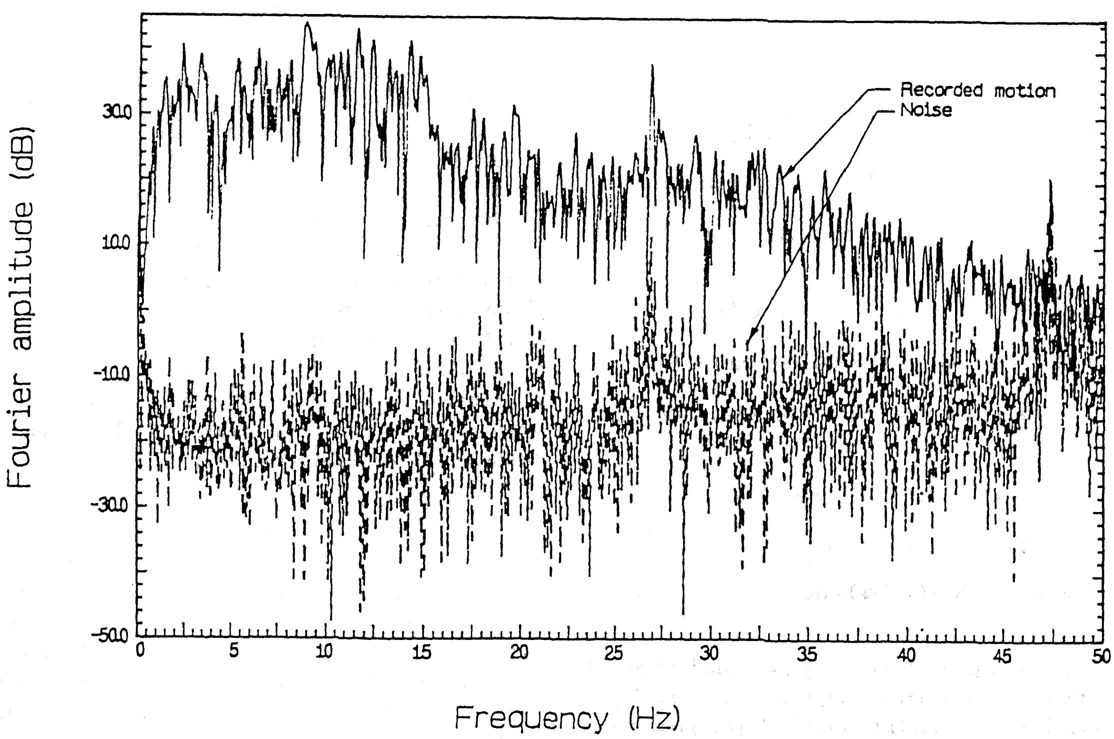

Figure 2: Comparison of Fourier spectra of raw data and noise

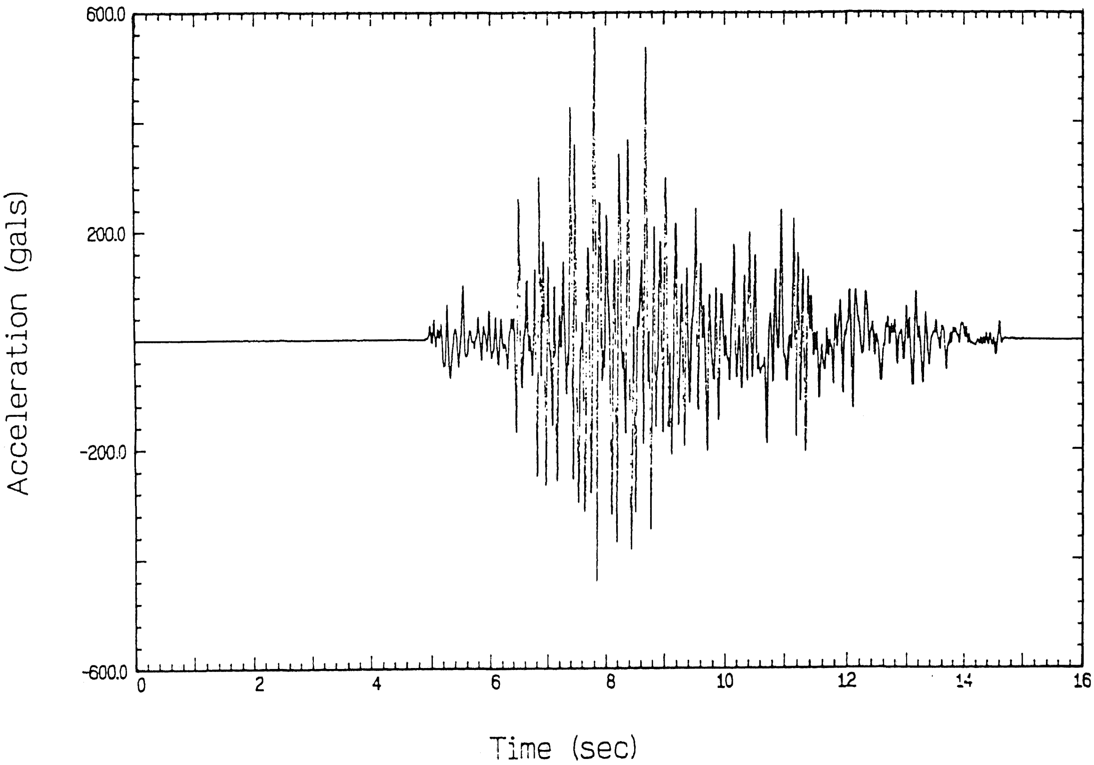

Figure 3: Corrected accelerogram of the entire history

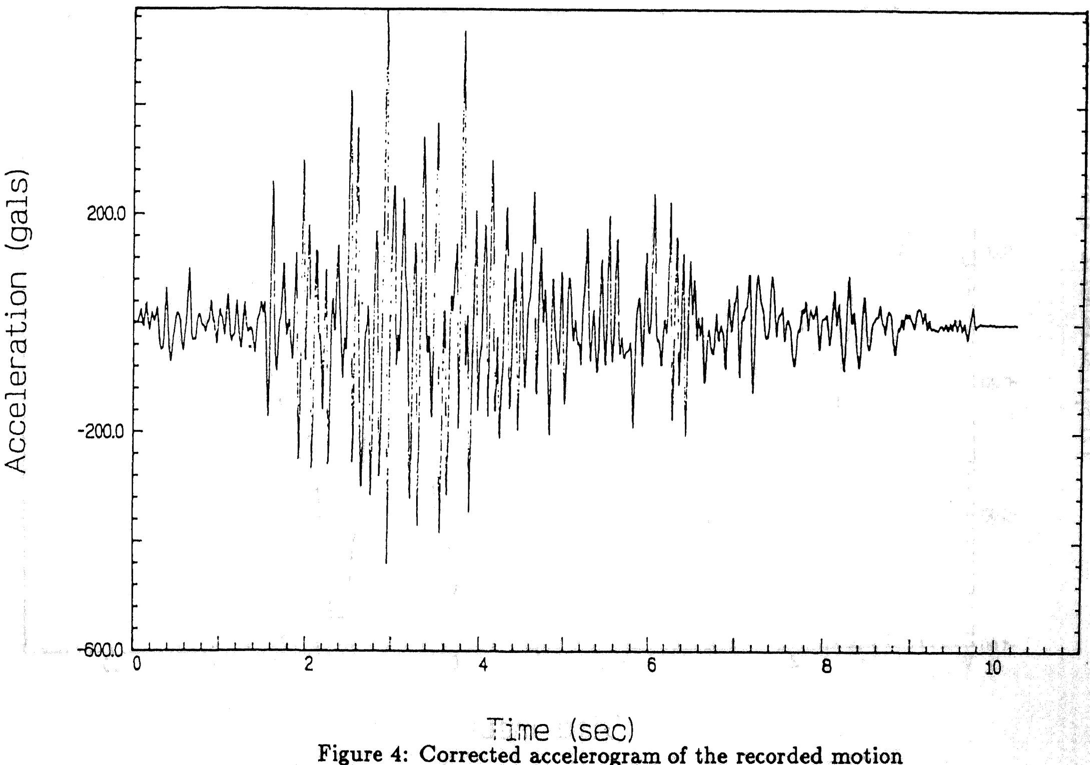

Figure 4: Corrected accelerogram of the recorded motion

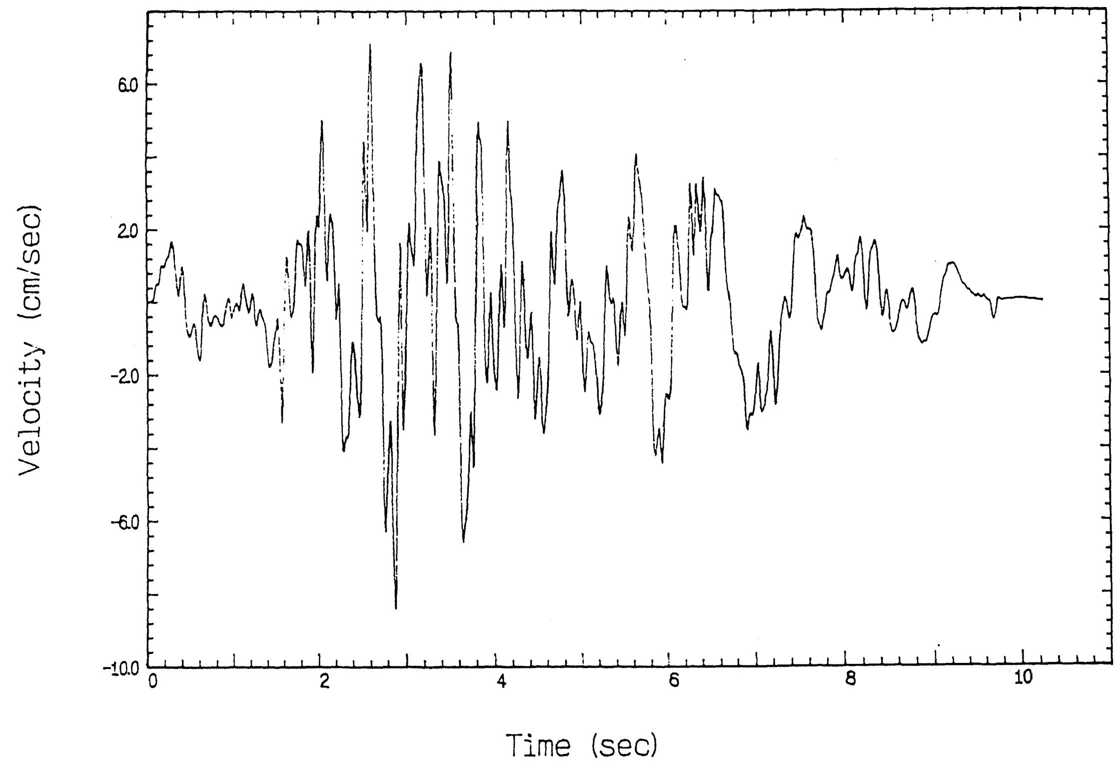

Figure 5: Corrected velocity of the recorded motion

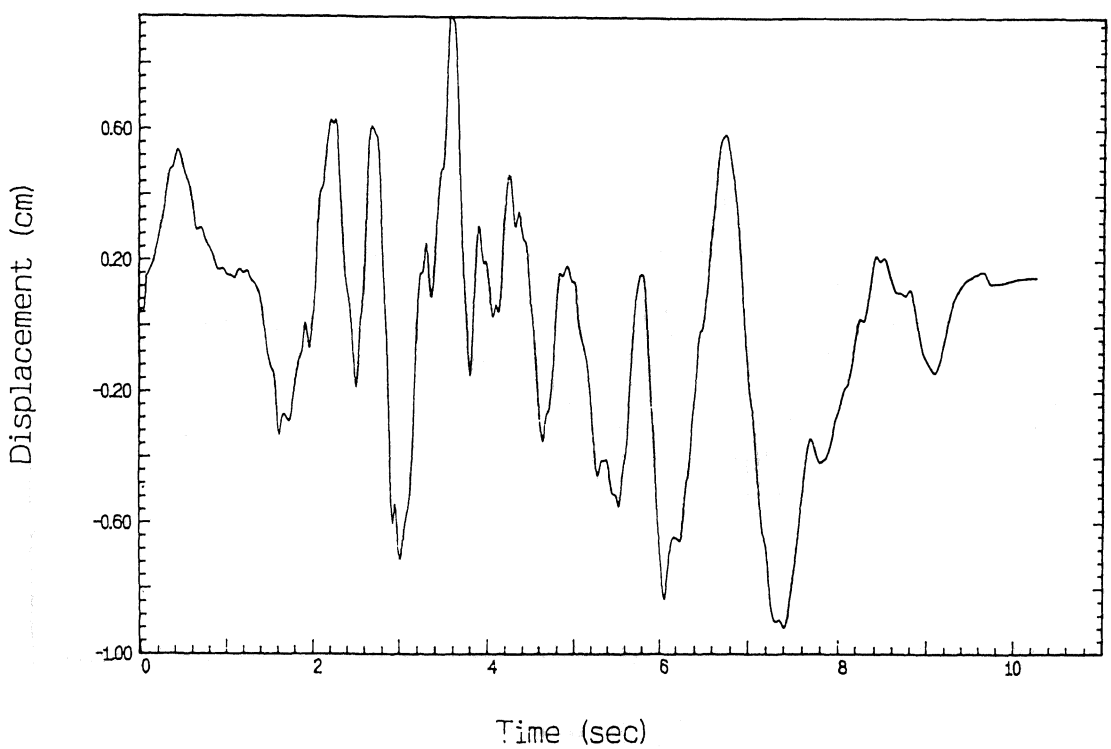

Figure 6: Corrected displacement of the recorded motion

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