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SHAKING TABLE EVALUATION OF STRONG MOTION DATA PROCESSING TECHNIQUES

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SUMMARY

The majority of available earthquake ground motion data has been obtained by processing measurements made with analog accelerographs. Each step of the process to generate information such as ground velocity, displacement, and response spectra introduces errors which can significantly affect the reliability of the results obtained.

Seismic simulation tests were performed to obtain analog acceleration records corresponding to ground motions which were also very accurately measured by other means. The accelerograms were then processed to predict the displacement history and response spectra of the table shaking. The errors introduced at each stage of the process were evaluated and attempts were made to develop procedures to mitigate the effect of these errors in the estimation of ground motion characteristics.

INTRODUCTION

Earthquake resistant design can only be possible if the characteristics of seismic induced ground motions can be reliably determined. Most of the information available to date has been obtained by processing acceleration records registered in photographic film by analog accelerographs. The film must be enlarged and digitized, and the resulting digital record must suffer substantial numerical manipulation to generate information such as ground velocities, displacements and Fourier and response spectra. Each stage induces errors which contribute to pollute the signal with increasing amounts of noise, thus reducing the reliability of the processed data. It is therefore crucial that processing techniques be devised which adequately reduce the noise levels in the seismic signals.

Even though several procedures have been proposed and developed for the "standard" processing of earthquake records (Refs. 1 and 2), there is no definite agreement about which is the most reliable technique for seismic data processing. For instance, Fig. 1 shows displacement response spectra corresponding to the Lima 1970 earthquake (N08E component) computed using the USGS methodology (Ref. 3) and a recently proposed technique (Refs. 4 and 5). Both methods predict similar spectral displacements in the period range of 0 to 4 seconds, but dramatically disagree in the longer period range.

The objective of this investigation was to study the most important error sources in the processing of strong motion records and to determine the impact of each type of error in the quality of the processed information. An attempt was also made to identify procedures capable of producing reliable earthquake data.

SHAKING TABLE TESTING AND SIGNAL PROCESSING

A strong motion analog accelerograph (SMA-1) was mounted on the seismic simulator at the Catholic University of Peru. The imposed table motion is presented in time and frequency domains in Figs. 2 and 3, respectively: it is representative of ground motions recorded on firm soil sites in the Peruvian coast. Horizontal platform acceleration and displacement were also measured with high accuracy with electronic transducers. Peak values of acceleration and displacement were 0.32 g and 30.6 mm, respectively. The frequency bandwidth of the signals was about 0 to 15 Hz.

The acceleration record obtained from the SMA-1 was developed, enlarged, manually digitized, and processed for baseline correction, digital filtering and numerical integration to obtain estimates of the table velocity and displacement. Separate studies of the errors associated with each step of the process were performed. The difference between predicted and measured table displacement was used to evaluate the effectiveness of the techniques employed. Finally, the influence of the processing methods on the computation of response spectra was briefly investigated.

ERRORS DUE TO NUMERICAL PROCESS

The main operation to predict velocity and displacement from an acceleration time history is, of course, numerical integration. It is well known that integration of a signal amplifies its low frequency components and attenuates the high frequency components. Low frequency noise present in the signal is therefore amplified by the integration process, regardless of the numerical algorithm employed. It seems thus reasonable to select a numerical integration scheme with good accuracy in the low frequency band and to high-pass filter the data to remove low frequency noise. (It is hoped that the filtering removes mostly noise: a drastic filtering procedure could also delete important information from the signal with possible disastrous consequences...)

The measured table acceleration time history, assumed to be free of noise, was used to predict table velocity and displacement. All errors were thus due to the numerical algorithms selected.

A constant baseline correction was first made to the acceleration record to remove any offset in the measurements and establish the zero acceleration level. Each integration stage was preceded by high pass filtering of the signal, to remove low frequency noise, and followed by a linear correction to eliminate linear trends in the data.

Numerical integration was performed using the trapezoidal rule, linear baseline correction consisted on a least squares fit, and filtering was performed in the time domain (with an Ormsby filter modified by a Kaiser window). Three high pass bands 0.05-0.07 Hz (USGS), 0.10-0.15 Hz, and 0.25-0.30 Hz were used, since the frequency band dominated by low frequency noise was not known.

Peak and RMS values of the difference between predicted and measured displacements (error signal) are presented in Table 1. The best results were obtained using a 0.10-0.15 Hz high-pass filter. Fig. 4 shows that the errors due to the integration process are relatively small and can be effectively removed by high-pass filtering the signals.

DIGITIZATION ERRORS

The measured acceleration record was accurately plotted to the same size as accelerograms enlarged for digitizing. The resulting graph therefore represented an acceleration trace free of the distorsions produced by film processing and instrumental errors. The acceleration trace was manually digitized by a single operator at a rate of about 100 points per second. Fig 5. shows the measured and digitized acceleration traces for a 1 sec. portion of the signal. The error due to digitization consisted in this case (it depends on the operator skill and the equipment used) of a systematic time shift and a seemingly random but small variation of amplitude. The frequency content of the error signal was found to be quite large, with significant low frequency components.

The digitized acceleration signal was subjected to the procedure described above to predict table velocity and displacement. The error values associated with this process are presented in Table 1. They represent the combined errors of the digitization and numerical processing stages. The best estimation of the table displacement was again obtained with the 0.10-0.15 Hz high-pass filter. The table displacement time histories computed using filtered and unfiltered digitized acceleration records are shown in Fig. 6.

FILM PROCESSING ERRORS

The SMA-1 film was developed and magnified four times in transparent medium. The acceleration trace was then digitized in four segments. This time, digitizing errors were larger than in the case of the plotted measured table acceleration, due to the thicker trace of the accelerogram signal.

Table velocity and acceleration were predicted with the selected procedure, except that a 0.15-0.20 Hz high-pass filter was used instead of the 0.25-0.30 Hz filter, which removed too much information from the signals. Displacement time histories generated with each filter are presented in Fig. 7. It is clear that low frequency noise due to film processing was very important, but could be practically eliminated with a 0.15-0.20 Hz high-pass filter. Except for distortions at both ends of the displacement time history (due to convolution in the filtering process) the table displacement estimated with the 0.15-0.20 high-pass filter was reasonably close to the measured table displacement.

RESPONSE SPECTRA

Acceleration, velocity and displacement response spectra were computed from the digitized accelerogram filtered at different high-pass frequency bands. Results obtained with the 0.05-0.07 "standard" band can be compared in Fig. 8 with those generated with the signal filtered at 0.10-0.15 Hz (which produced the best estimate of table displacement). Spectra obtained from measured acceleration, also shown, were assumed to be correct. All spectra were computed for 5% damping.

The spectra computed with the 0.05-0.07 filter showed relatively small errors in the low period range of 0-3 sec. For longer periods, acceleration spectral values were reasonable, the velocity spectrum showed significant errors and the displacement spectral values were unacceptably large. The spectra computed with the 0.15-0.20 filter gave adequate results in the whole period range considered.

CONCLUSIONS

- The numerical algorithms selected for integration, baseline correction and digital filtering introduced very small error in the process. Errors due to film processing and manual digitization of the accelerogram were responsible for most of the noise in the signal.
- Most of the effects of the low frequency errors within the signals can be removed by filtering with an appropriate high pass frequency band. Adequate selection of the filtering band is therefore a crucial step in the process. Unfortunately, not enough data is currently available to determine the best filtering parameters for "real" earthquakes.
- Low frequency errors in the acceleration record introduced significant distortion in the response spectra for periods longer than approximately 3 seconds. Most "reasonable" signal processing methods will thus produce adequate results in the low period range, but extreme care must be exercised when using seismic information in the long period range.

ACKNOWLEDGMENTS

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ERROR SOURCE	NUMERICAL FILTER	ERROR (mm)	
		Peak Value	RMS
Numerical *Process*	No filter	11.49	7.02
	0.05-0.07	*6.61*	*2.75*
	0.10-0.15	2.59	1.53
	0.25-0.30	11.18	5.52
Digitization	No filter	39.81	24.30
	0.05-0.07	24.56	12.25
	0.10-0.15	13.70	5.24
	0.25-0.30	11.38	5.48
Film Processing	No filter	688.74	321.37
	0.05-0.07	147.74	69.40
	0.10-0.15	22.52	8.56
	0.15-0.20	17.00	4.97

Table 1: Errors in acceleration record processing
Peak measured displacement: 30.6 mm

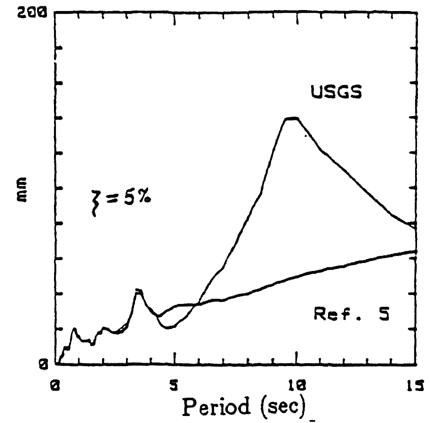

Fig. 1 Displacement Response Spectrum
Lima 05/31/70 T comp.

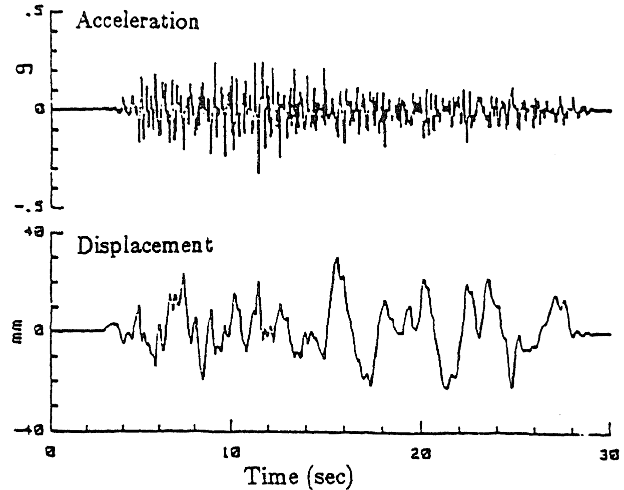

Fig. 2 Shaking Table Motion

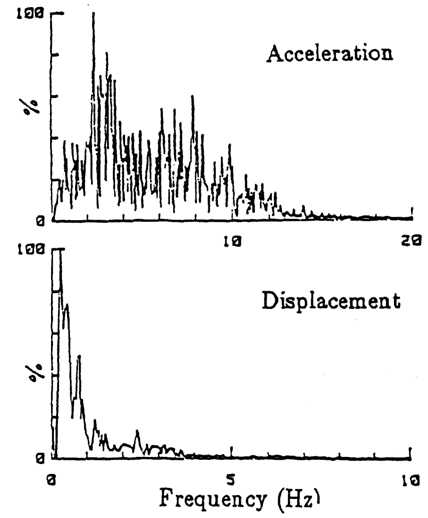

Fig. 3 Fourier Amplitude Spectra

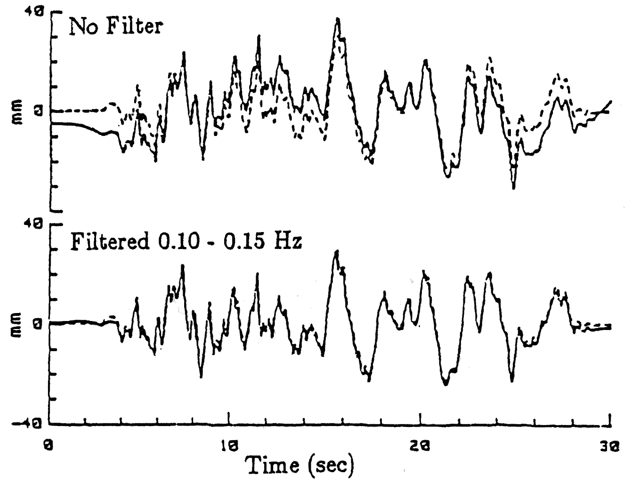

Fig. 4 Displacements Computed from Measured Accel.
(dashed: measured)

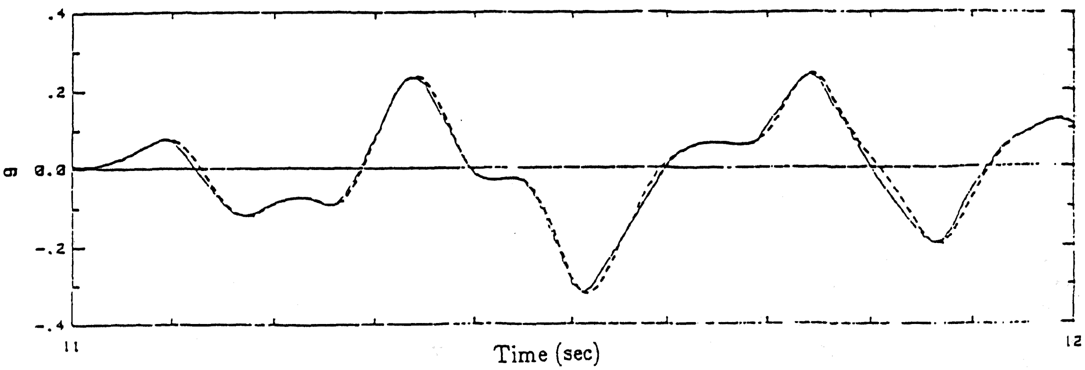

Fig. 5 Acceleration Digitization Error
(dashed: measured)

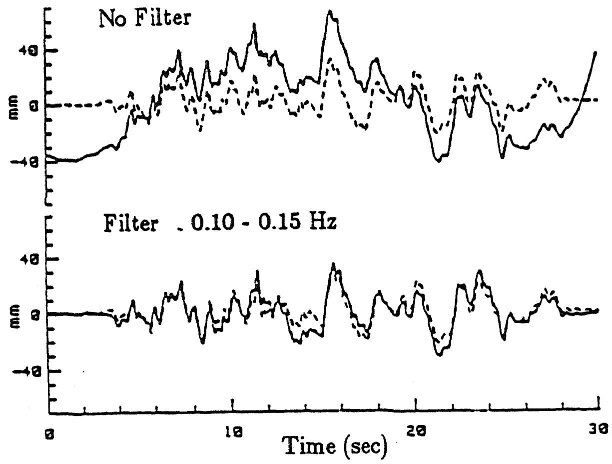

Fig. 6 Displacements Computed from Acceleration Plot
(dashed: measured)

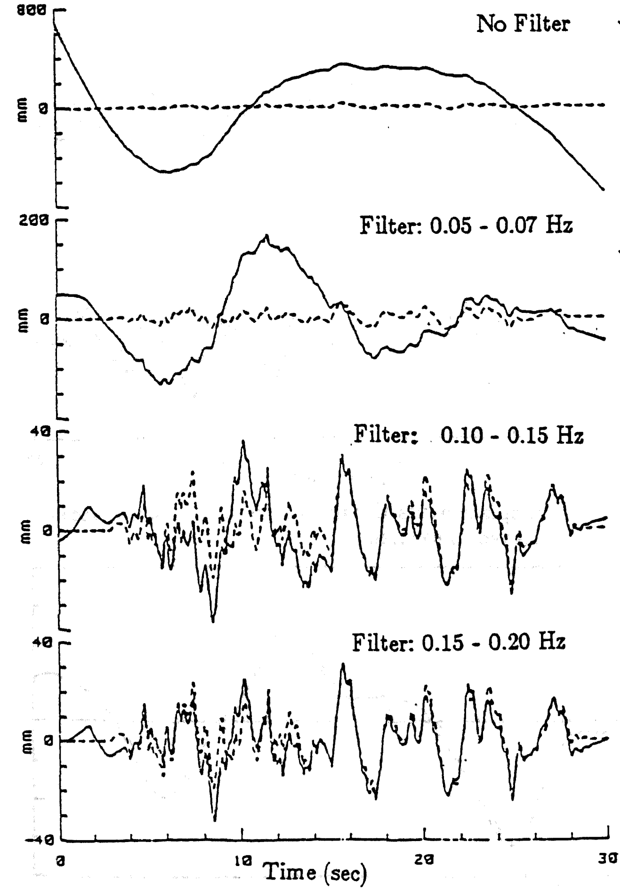

Fig. 7 Displacements Computed from Film Acceleration Record
(dashed: measured)

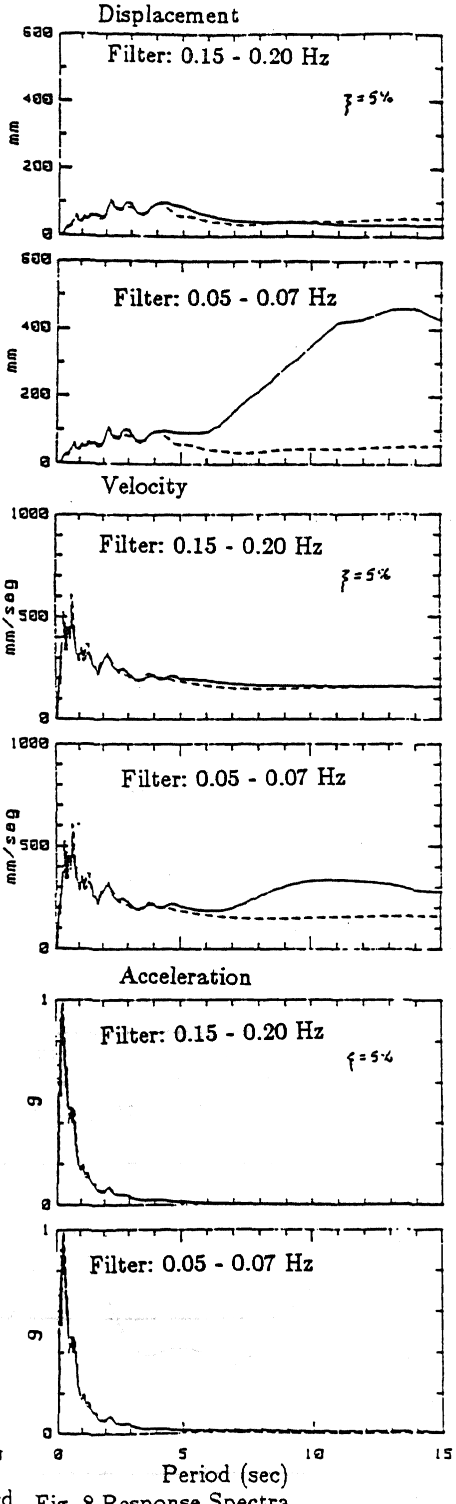

Fig. 8 Response Spectra
(dashed: from measured acceleration)