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EARTHQUAKE RECORDS AND DESIGN

THE CALIFORNIA STRONG-MOTION INSTRUMENTATION PROGRAM: STATUS AND GOALS

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INTRODUCTION

The California Strong Motion Instrumentation Program (SMIP) was established following the destructive 1971 San Fernando earthquake to increase the limited set of data on strong earthquake shaking. The program installs and maintains strong-motion recorders in representative structures and geological environments throughout the state. Strong-motion data recovered from the instruments is processed and made available to engineers and seismologists involved in predicting or designing for earthquake shaking. The goal of the strong-motion program is to provide the data necessary to improve seismic codes and increase seismic safety.

Since the inception of the program a total of nearly 400 installations of various types have been completed (Figure 1). Stations and buildings are selected for instrumentation on the basis of recommendations of a program advisory committee of the Seismic Safety Commission. Various organizations and professional groups provide input to the advisory committee.

TYPES OF STRONG-MOTION INSTALLATIONS

Free-Field Stations

In general, strong-motion installations can be divided into three types. The first category consists of the free-field or ground response stations, which are the simplest to install.

Figure 2 shows a typical modern free-field installation. The instrument housing is, in this case, a light plexiglass enclosure approximately 3 feet high. (This housing is actually an adapted transformer housing and, thus, is often called a "T-Hut".) The base is a 4 ft by 4 ft reinforced concrete pad, approximately 4 inches thick, with a central raised surface on which the instrument is mounted. Near each corner the concrete extends to a depth of about 18 inches in a cylindrical shape approximately 8 inches in diameter. The goal of this design is to affect the incoming ground motion as little as possible, while at the same time providing adequate coupling to the ground and environmental protection for the instrument. Most stations of the Parkfield strong-motion array, from which nearly 50 records were recovered after the 1983 Coalinga earthquake, are T-Hut installations.

While most recent free-field installations are of the type indicated in Figure 2, earlier installations typically consist of an accelerograph bolted to the floor of a small, usually wood-frame, structure. Fire stations were often used for this purpose. These installations are probably not as free of ground interaction effects as the T-Hut sites.

In addition to surface ground response measurements, subsurface or downhole measurements are of increasing importance. The art of downhole accelerography is not as well developed as for surface instruments. The Strong Motion Program installed four downhole systems during the late 1970's. At this time, only one is operational and it appears to be failing. This is an area of instrumentation posed for significant progress in the near future.

Building Instrumentation

The second category of instrumentation includes the building installations. These are characterized by distributed sensors cabled to a central recorder which is typically located in a closet or other small room. At the time of the 1971 San Fernando earthquake, an instrumented building usually had one triaxial accelerograph located on the top floor of the building, one at mid-height, and one at the base or ground floor of the building. This arrangement is still indicated in the Uniform Building Code. Practically, analyses of the San Fernando data indicated that the records would be of much greater value if the time axis for all the data were common and if recordings of the building motion were obtained from more than these three locations. From that understanding the Central Recording Accelerograph system evolved. With this system sensors can be located almost anywhere within a building and connected, via shielded cabling, to a central recording unit that records all of the signals on a single film.

The most important structural distributed-sensor record obtained by SMIP are those from the El Centro County Services Building that document the strong-shaking and associated structural failure of this modern multi-story building during the 1979 Imperial Valley earthquake. These records have received extensive analyses and are discussed elsewhere in this seminar.

Another example of distributed-sensor structural response records is the set of records obtained from the Mammoth Lakes High School Gymnasium. The response of this simple structure has been recorded repeatedly during the recent earthquakes in the region. Figure 3 shows schematically the sensor locations in the structure. Figure 4 shows the recorded motion from the ten sensors during the 5.5 ML earthquake of 6 Jan 1983, less than 5 km away. The wealth of information and comparisons that can be made from a record of this type, even without digitization and processing, is readily apparent.

Lifeline Instrumentation

The third category of installations includes lifelines and related structures. These are similar to building installations except that the instrumentation is often not as environmentally protected as in a building, and the total installation may have a significant linear extent. This category includes structures such as bridges, dams, tunnels. Because the sensors and much of the cabling is often exposed to the elements, maintenance is generally more of a problem than with buildings.

An example of a well-instrumented bridge whose seismic response has been repeatedly measured is the Highway 101 overpass in Rio Dell, near Eureka. A schematic of the instrumentation layout is shown in Figure 5. The vertical acceleration recorded at the center and ends of each of the spans is shown in Figure 6. Records like these are very important to improved understanding of the behavior of bridges during strong shaking.

INSTRUMENT OPERATION AND MAINTENANCE

The maintenance of strong-motion instrumentation is an art that has been developing since the early 1930's. Since that time it has been understood that thorough training and careful, regular servicing are the keystones of an effective maintenance program. With regard to free-field stations, practical details such as keeping batteries outside the instrument itself are still important. The T-Hut configuration for free-field stations has evolved partly because it allows careful and clean maintenance procedures. As a power source, solar panels are becoming increasing economical, and now represent a small percentage of the total installation cost. However, they lead to deeper cycling, and possibly a shorter life, for batteries.

Recording the time of the instrument trigger remains a problem not completely solved. The reception of the WWVB radio time code, which depends on atmospheric conditions, is insufficiently reliable. Internal clocks are seeing wider application, and more experience will indicate whether they yield an adequate performance level. Probably the most attractive concept is an internal clock which is periodically updated by a radio time signal. This system is not presently economical for routine use.

The recording of trigger time on an accelerogram is very important. Besides providing detailed information about the earthquake for seismological studies, it provides the only way to associate a record with a particular earthquake when several events occur over a short period of time. This is very common during aftershock sequences, and occurred even for the principal events in the 1980 Mammoth Lakes and Livermore earthquakes. Being unable to establish which earthquake a strong-motion record is associated with significantly reduces the value of that record.

The central recording accelerograph is a recent introduction to strong motion instrumentation. It does not, therefore, have the long history of improvements which lead to the high reliability of the analog accelerograph. At this time, central-recording systems tend to exhibit a lower reliability than the standard accelerograph.

ACCELEROGRAM PROCESSING

The Strong Motion Instrumentation Program began developing an in-house digitization capability in the late 1970's, as the data being recovered became too voluminous for the USGS cooperative program to continue processing. The digitization system used by SMIP is patterned after that developed by Trifunac and Lee at the Univ. of Southern California. This system can be classed as a global-scanning system, that is, the entire film is optically scanned, with a separate trace-reconstruction step following the scanning. A system like this is shown schematically in Figure 7. Automatic scanning systems are probably the biggest difference between digitization now and at the time of the San Fernando earthquake. These systems can digitize records much more economically than the manual systems. Digitization-noise analyses are also more economical to perform. Digitization noise is, of course, always present - the important thing as a user of the data is to appreciate its presence. A goal in processing, of course, is to keep the noise as low as possible.

Ongoing investigations and improvements of the SMIP processing system have led to a significant lowering of the system noise floor. The present noise levels for acceleration, velocity and displacement are shown in Figure 8. These were obtained by digitizing straight-line reference traces on accelerograms as though they were data traces. The curves indicate that the acceleration noise is approximately constant at about .002 g (approximately the digitization step-size), independent of frequency. The velocity noise increases with period, but the displacement noise increases more rapidly with period. Noise levels of as much as 1 cm in amplitude are present in the displacement at long (10 sec) period, but only a tenth of a centimeter in amplitude at 1 Hz. For comparison to the response spectra from actual records, Figure 9 shows the response spectrum resulting from the fixed-trace digitizations. Note that Figures 8 and 9 only include noise due to digitization; any noise arising from the instrument itself would not be included.

PROGRAM STATUS AND FUTURE PLANS

The current recommendations of the program advisory committees regarding the number of installations needed to provide minimum adequate instrumentation for each installation type are shown in Table 1. The numbers of installations presently in place are also listed. The ground-response and dams categories are much nearer to completion (70%) than the buildings category (15%). This reflects the start of the building instrumentation phase of the program in 1976, after the first years of the program were devoted to the rapid deployment of ground response stations throughout the state.

Given the planned totals in Table 1 and revenues based on a good construction year (80-81), projections have been made of how long it will take to complete the installations called for in Table 1; Figure 10 shows those projections. Figure 10 demonstrates that even with the 80-81 healthy-construction assumption, approximately 100 years will be required to complete the proposed installations. In that case, the structural response data recovered from the planned installations would probably become available long after the occurrence of the major earthquake we are trying to design against.

The program advisory board suggested that cost projections for an accelerated installation schedule be developed. These results indicate that the 100-year installation time shortens to approximately 20 years if the strong-motion fee is increased from 7 cents to 14 cents per $1000 of construction costs during those 20 years. In that case, all the slated installations would be in place by shortly after the turn of the century. This would hopefully ensure recording the strong-shaking during the often-cited imminent major earthquake. These aspects are under consideration by the advisory committees and are scheduled for discussion by the California Seismic Safety Comission.

SUMMARY

During the past 12 years, the California Strong Motion Instrumentation Program has installed over 400 stations in a variety of structures and geologic environments. A large volume of strong-motion records have been recovered, including the very important records from the El Centro County Services Building and the Parkfield strong-motion array. Digitization of accelerograms is a more recent program activity, but many records have already been processed for distribution and detailed analysis. Catalogs listing all records recovered and the subset of records digitized are maintained and available on request. Visits or inquiries concerning installation techniques or other practical matters are welcomed.

Future installation activity by SMIP will be heavily weighted toward the instrumentation of buildings and other constructed facilities, including lifelines. Instrumentation, at the present time nearly all analog, will shift to digital as soon as reliability and costs approach those of analog equipment. The digital equipment will remove the expensive step of film digitization.

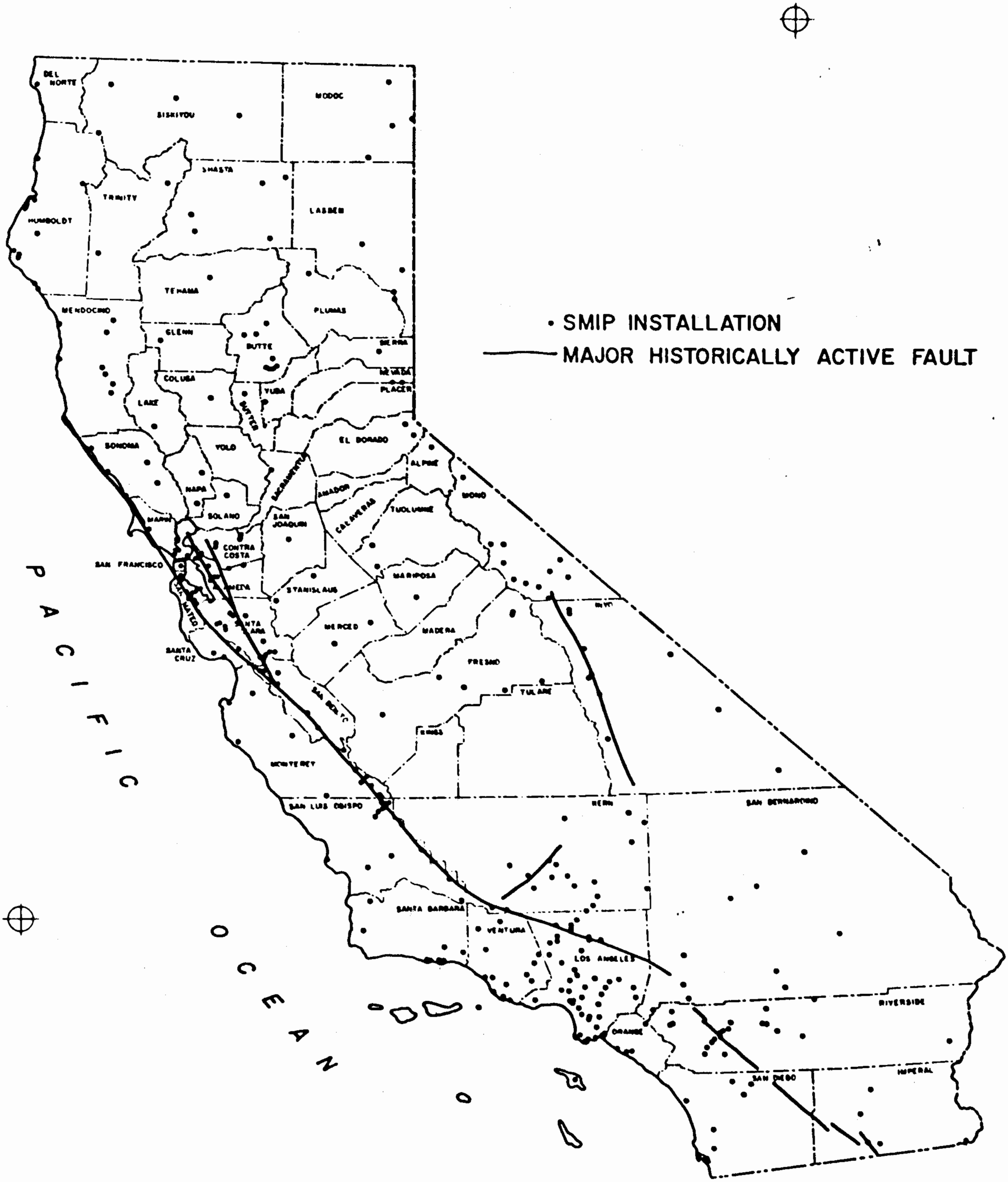


Figure 1 - SMIP Strong-motion stations in California

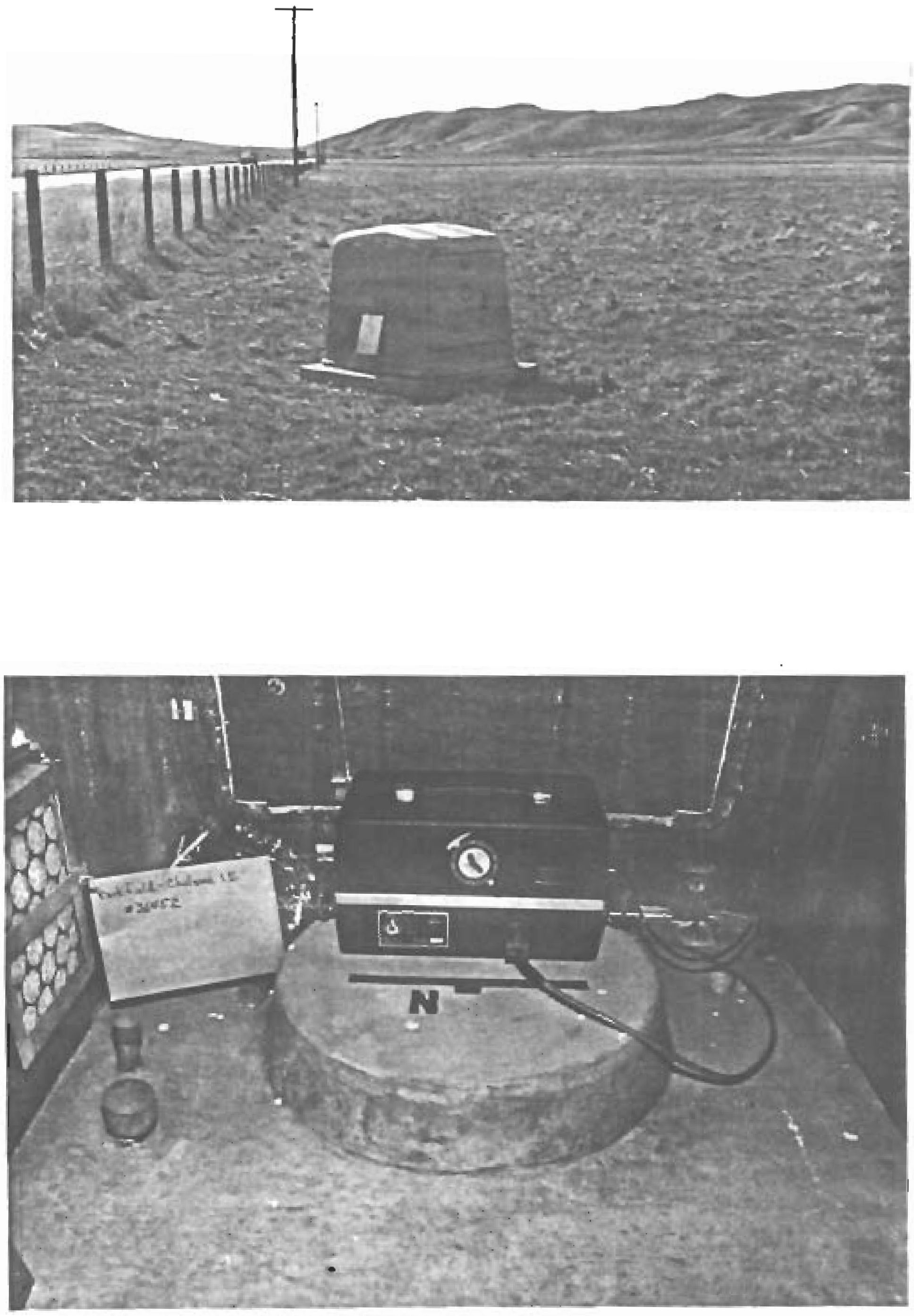
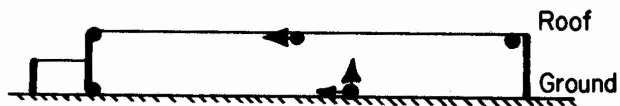
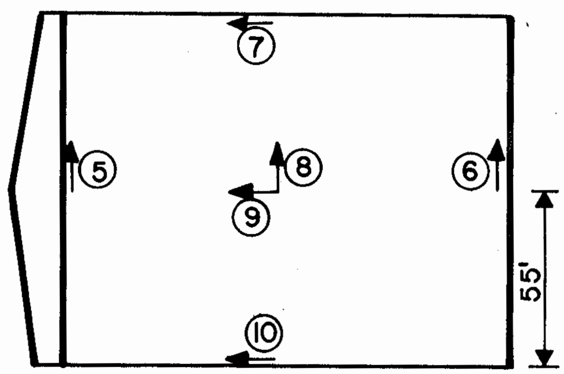


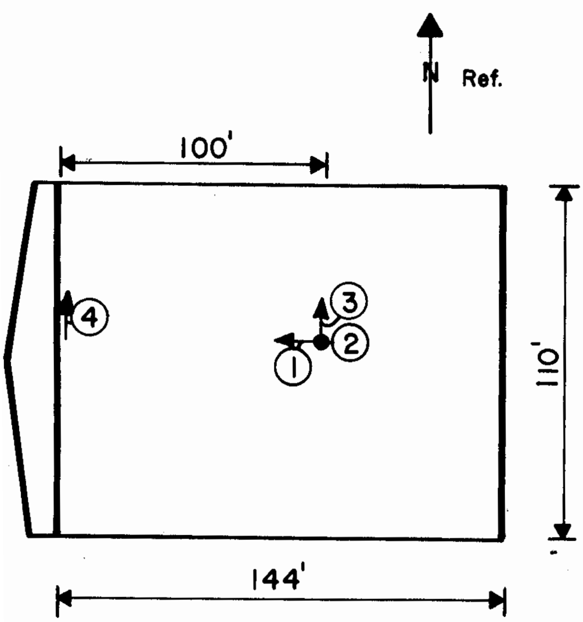
Figure 2 - (Upper) Typical free-field station showing fiberglass housing.
(Lower) Internal view showing accelerograph and reference orientation line.



W-E Section



Roof Plan



Ground Floor Plan

Installation Notes:

Accelerometers 1,2,3 and 4 are installed on the ground floor slab.

Accelerometers 5,8 and 9 are attached to the roof trusses at the bottom chord level.

Accelerometers 6,7 and 10 are attached to the roof trusses at the top chord level.

Recorder trace order:

Accelerometer	1
Fixed trace	-
Accelerometer	2
" "	3
Fixed trace	-
Accelerometer	4
" "	5
Fixed trace	-
Accelerometer	6
" "	7
Fixed trace	-
Accelerometer	8
" "	9
Fixed trace	-
Accelerometer	10

Lateral Force resisting system:

Horizontal steel bracing in plane of lower chord of roof trusses; vertical steel bracing encased in reinforced concrete exterior walls.

Figure 3 - Mammoth High School Gymnasium, strong-motion instrumentation scheme.

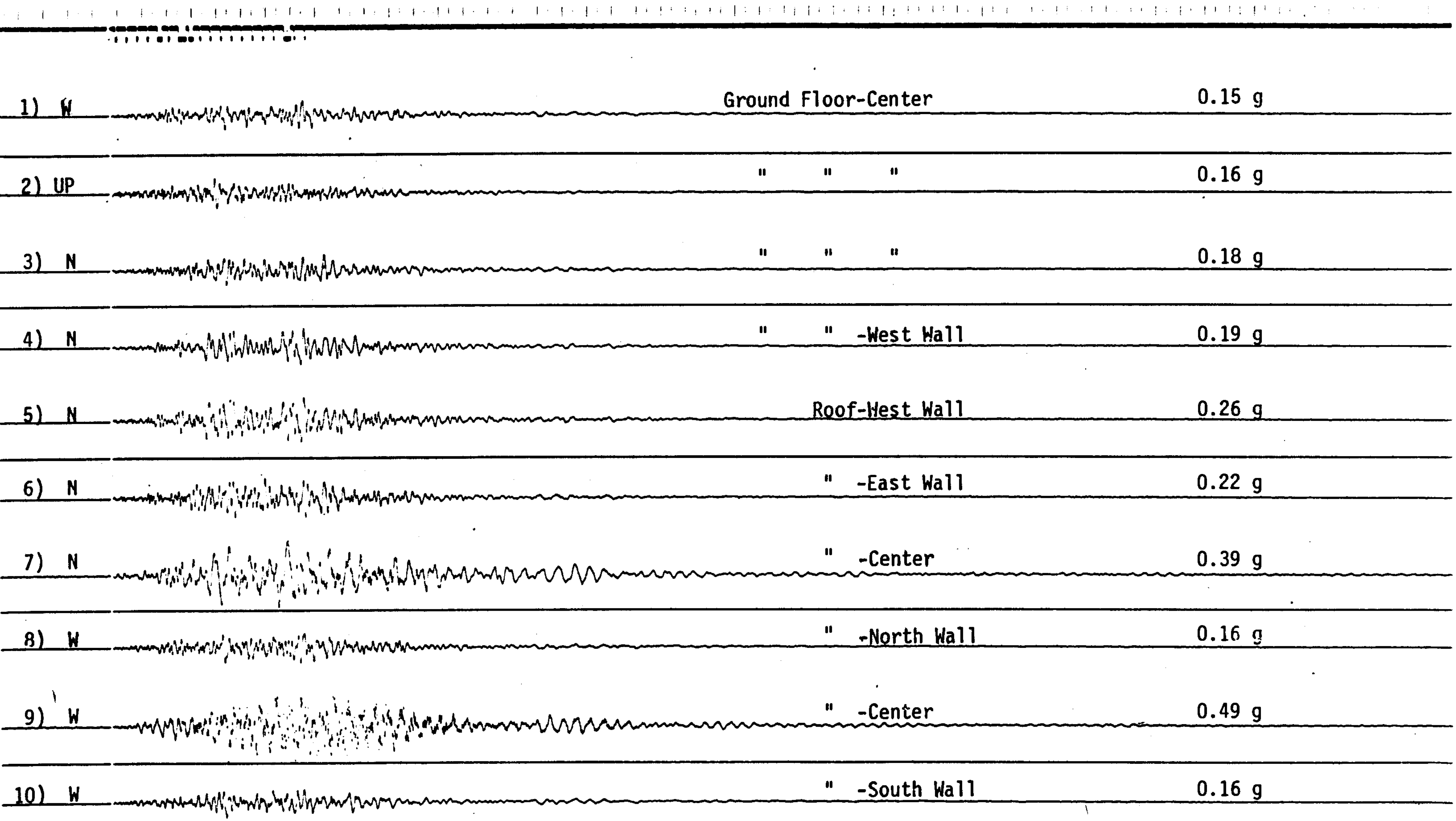
ACCELEROGRAMS

The accelerograms reproduced on the following pages record strong motions that occurred during three distinct events--one on 25 May 1980 at 0933 hours ($M_{6.5}$), one on 25 May at 1245 hours ($M_{6.7}$), and one on 27 May at 0751 hours ($M_{6.3}$). These three events produced the highest peak accelerations recorded on CDMG-SMIP instruments during the entire earthquake sequence with the one exception of the Convict Creek instrument. The $M_{5.5}$ event on 25 May at 1336 hours generated a peak acceleration of 0.49 "g" on the horizontal accelerometer oriented at 180° azimuthal.

The accelerograms contained in this report are presented in three sections, with one section for each event. Each accelerogram is labeled with station number, station name, date and time (PDT) along with trace azimuth orientation and decimal fraction of "g" (circled, on accelerometer trace).

Mammoth Lakes-High School Gym
CDMG Station #54301
Record #54301-C0135-83007.05

Mammoth Lakes Earthquake of
6 Jan 83-19:24 (PST)



Structure Reference Orientation: N=344°

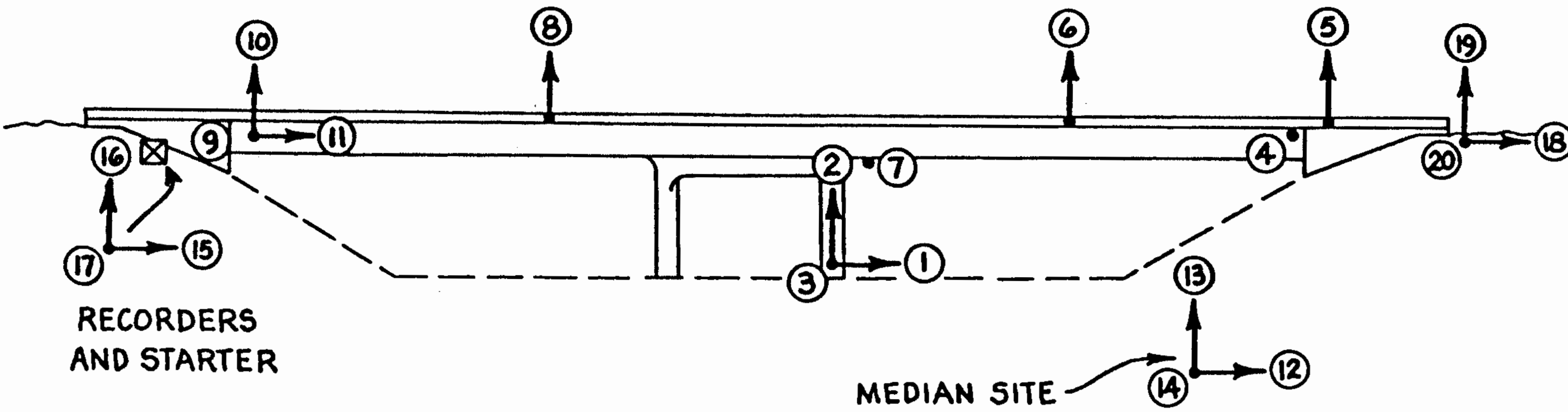
Figure 4

Timing: 2 marks/sec

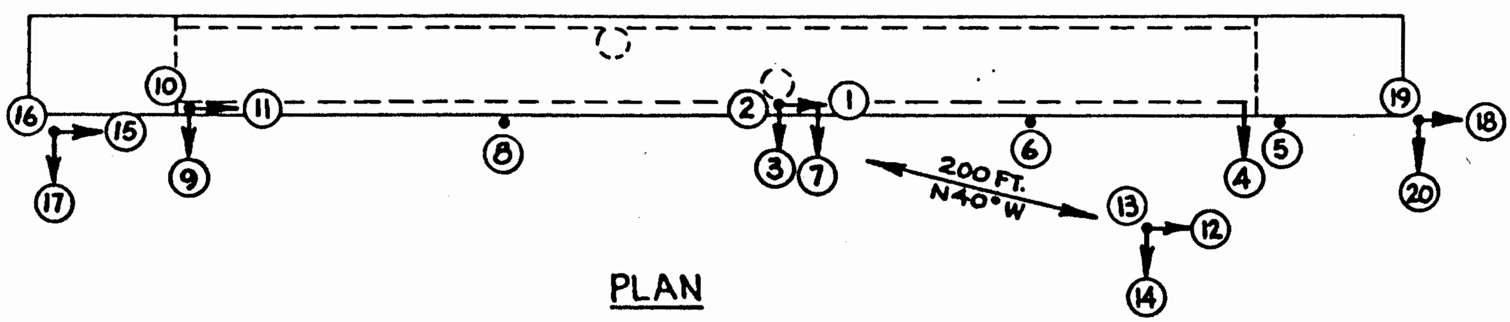
RIO DELL

HIGHWAY 101 OVERPASS

STRONG MOTION INSTRUMENTATION SCHEME



ELEVATION
VIEW NORTH



PLAN

Figure 5

NOT TO SCALE

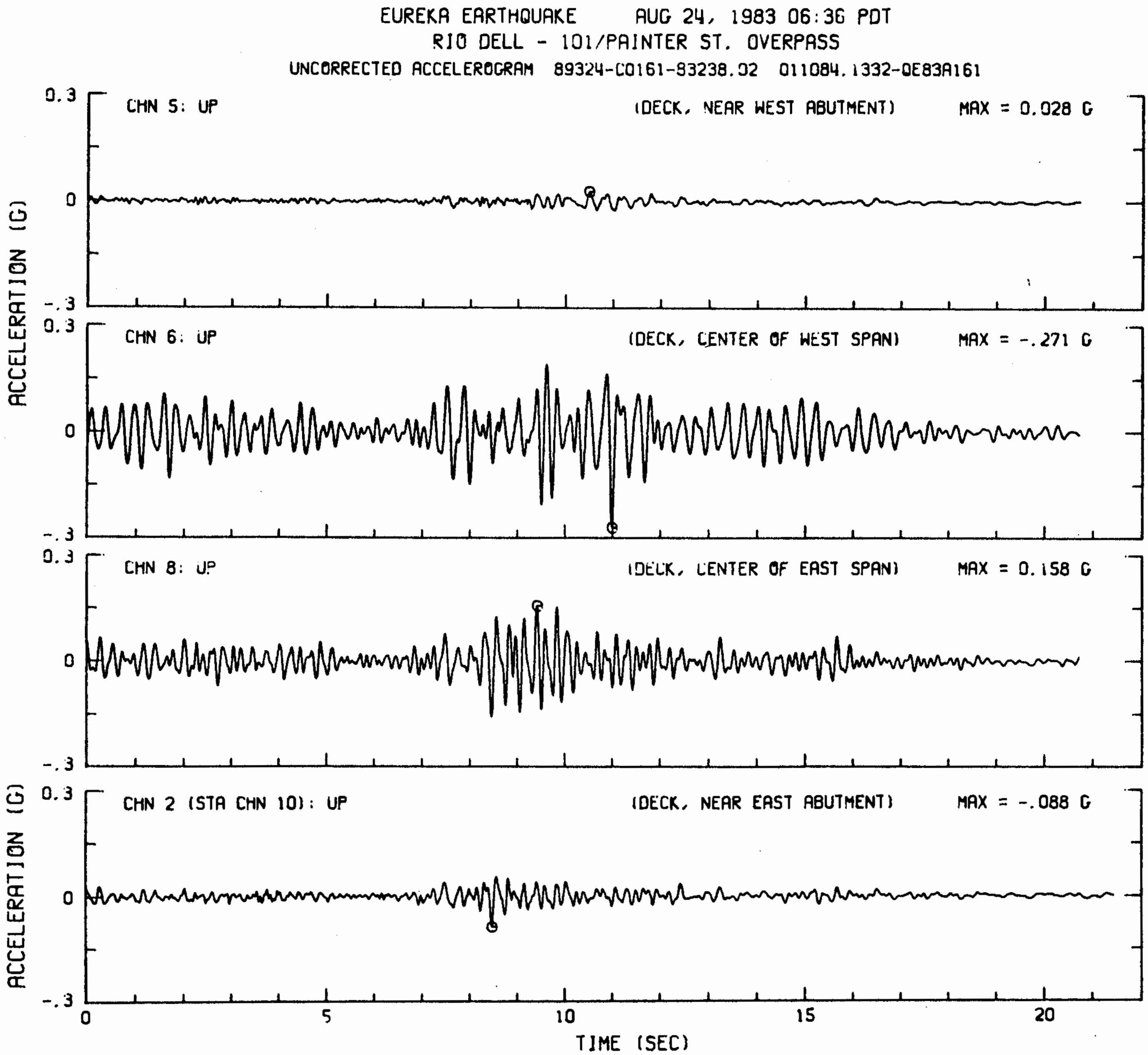


Figure 6 - Acceleration records, vertical channels, from the Highway 101 overpass in Rio Dell, near Eureka.

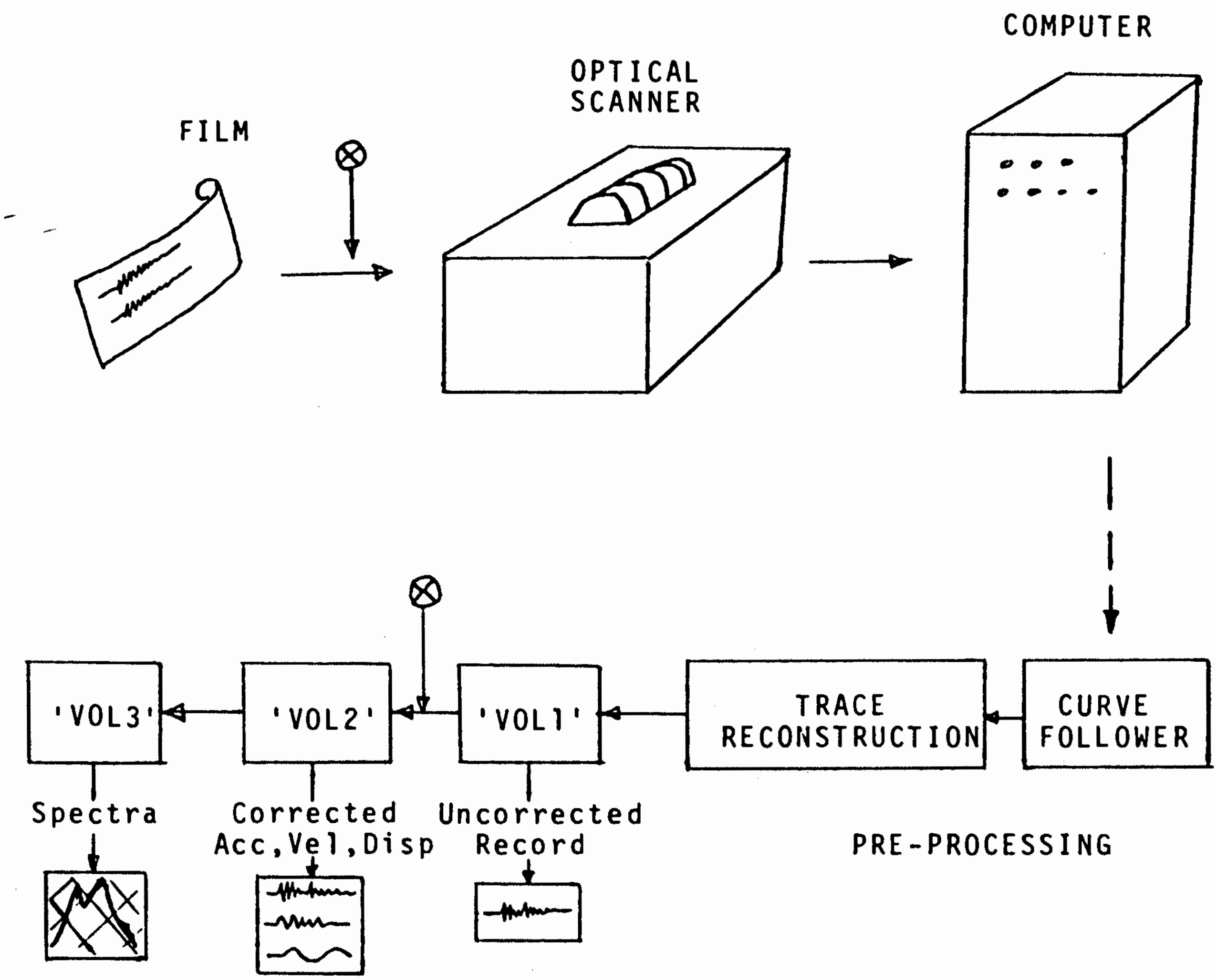


Figure 7 - Flowchart of accelerogram digitization and processing steps.

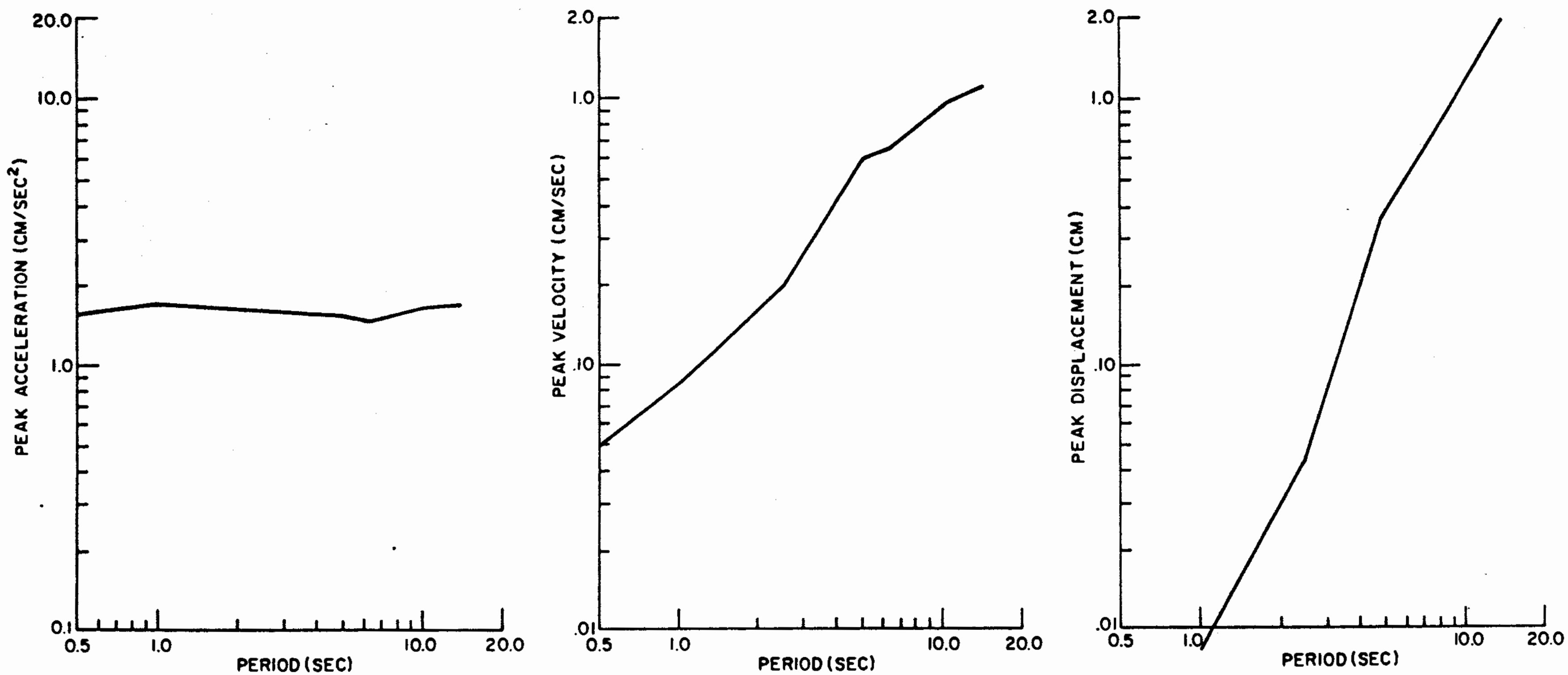


Figure 8. Processing noise present in a typical acceleration (left), velocity (middle) and displacement (right) record processed with a long-period filter cut-off period ranging from 0.5 sec to 15 secs.

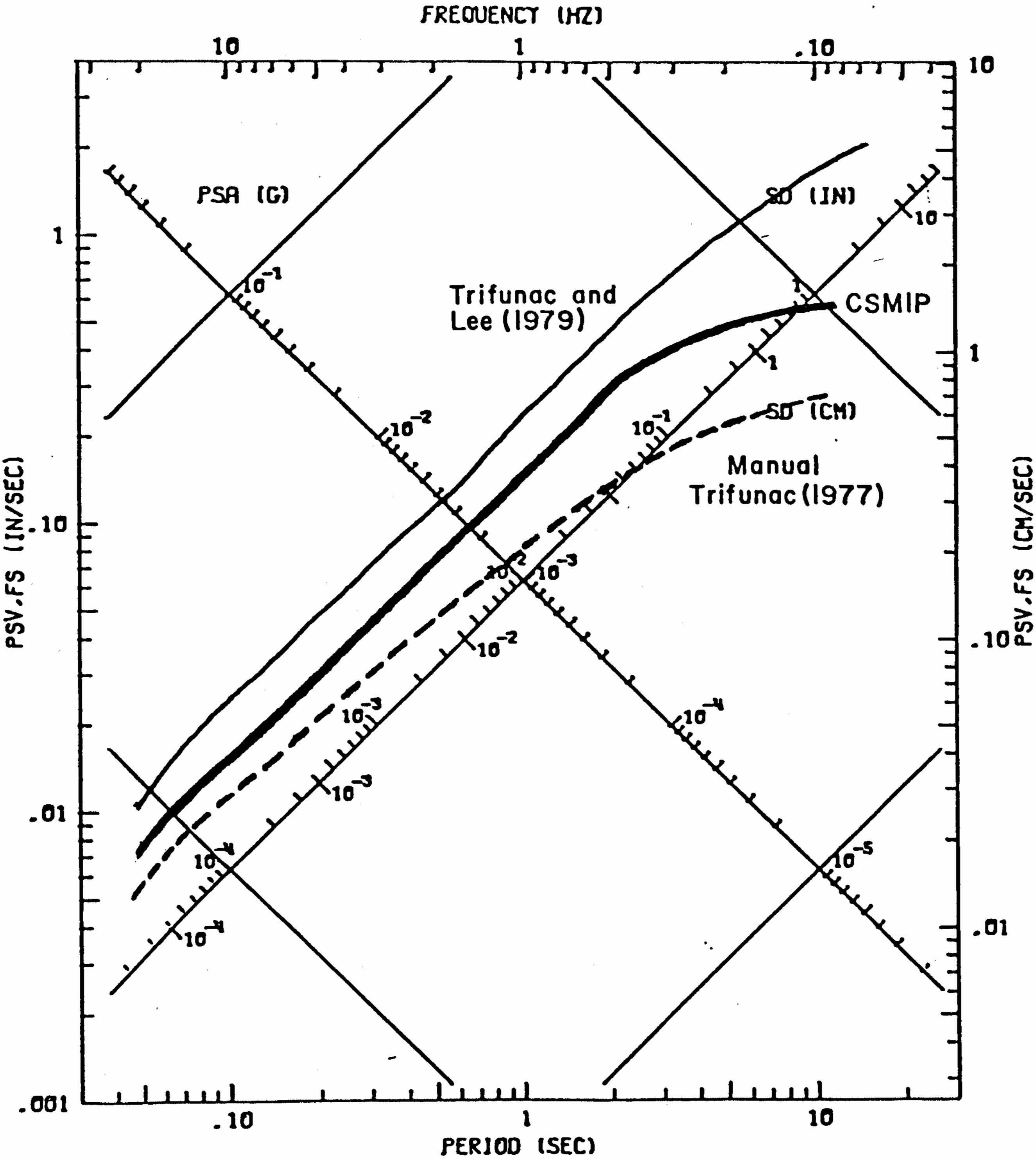


Figure 9. Noise-level spectra (PSV, 20% damping) for the CSMIP (heavy line) digitization system compared to other spectra from the literature.

TABLE 1

SMIP INSTALLATIONS - PRESENT STATUS

Station Type	Planned Total	Stations Completed	% Completed
Ground Response:			
Isolated Sites	400	297	74%
Special Arrays	20	0	0%
Buildings	400	56	14%
Dams	30	21	70%
Transportation	40	5	12%
Water & Power Facilities	25	0	0%
TOTALS	915	379	

SMIP INSTALLATION COMPLETION SCENARIO

GIVEN 80-81 INCOME LEVEL

FEE RATE: 7¢/$1000

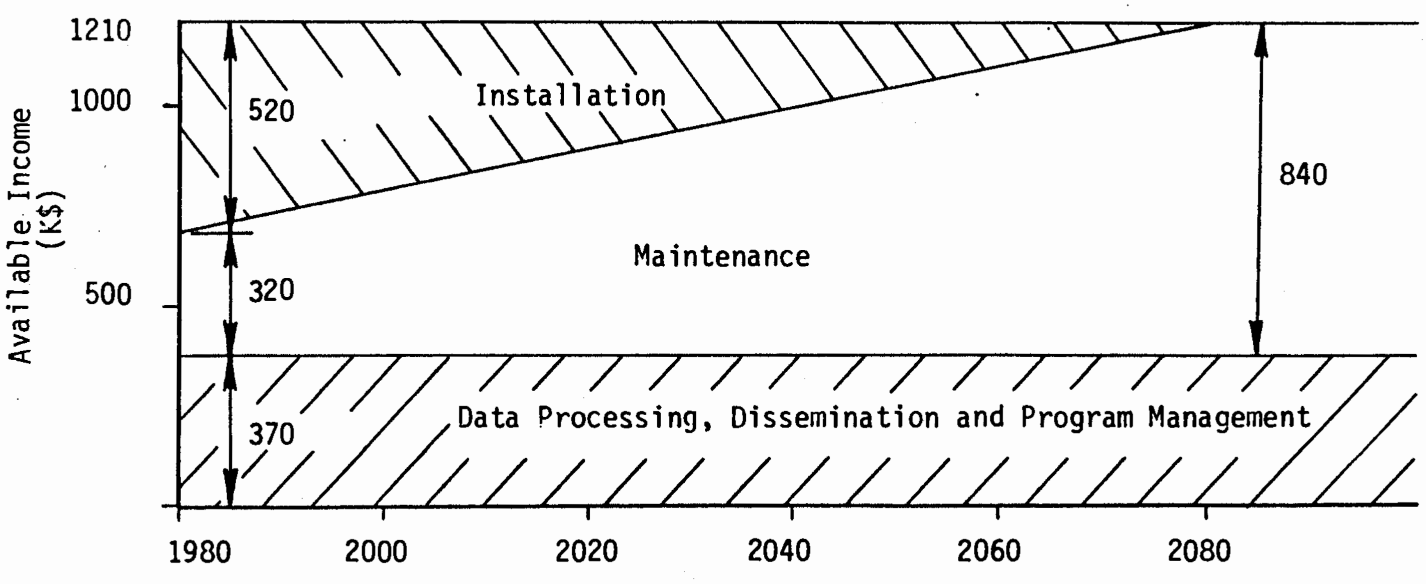


Figure 10