PB 260 556

REPORT NO.
EERC 76-6
MARCH 1976

EARTHQUAKE ENGINEERING RESEARCH CENTER

TIME AND FREQUENCY DOMAIN ANALYSES OF THREE DIMENSIONAL GROUND MOTIONS SAN FERNANDO EARTHQUAKE

by

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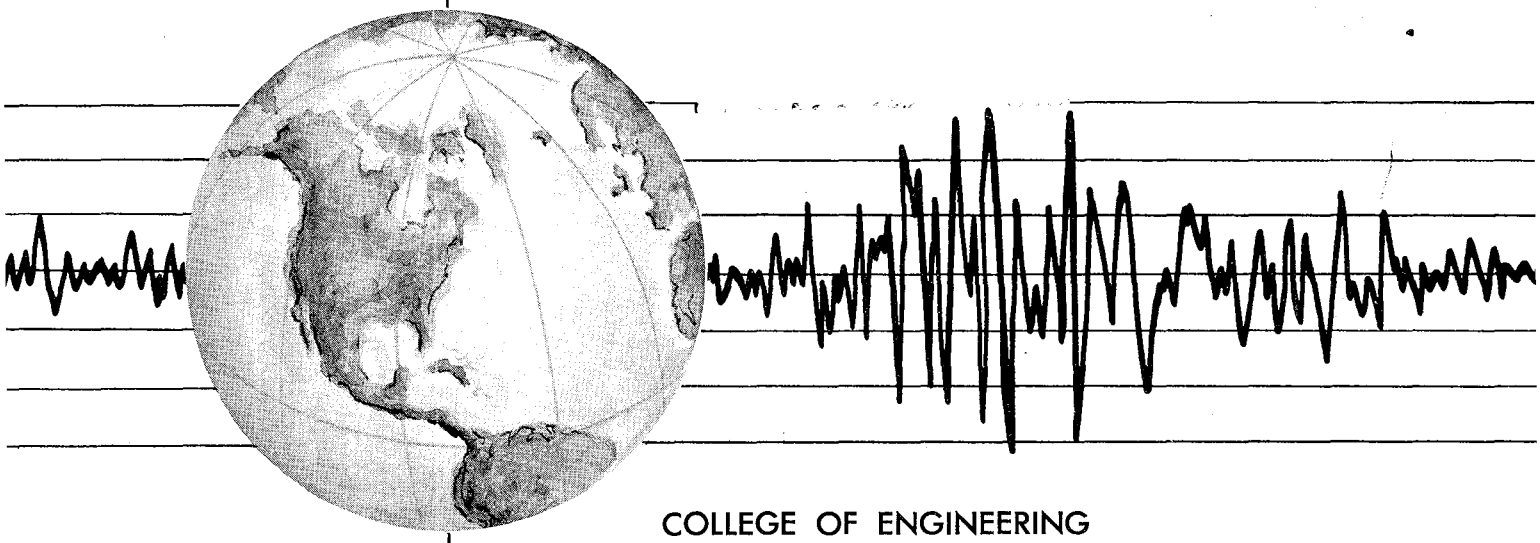
Report to the National Science Foundation



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BIBLIOGRAPHIC DATA SHEET	1. Report No. EERC 76-6	2.	3. Recipient's Accession No.
4. Title and Subtitle "Time and Frequency Domain Analysis of Three Dimensional Ground Motions San Fernando Earthquake"			5. Report Date March 1976 6.
7. Author(s) Tetsuo Kubo and Joseph Penzien			8. Performing Organization Rept. No. ~~76-10~~
9. Performing Organization Name and Address Earthquake Engineering Research Center University of California, Berkeley 1301 S. 46th Street Richmond, California 94804			10. Project/Task/Work Unit No. 11. Contract/Grant No. GI-36387
12. Sponsoring Organization Name and Address National Science Foundation 1800 G Street Washington, D. C. 20550			13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstracts

Principal directions and components are generated for the strong ground motions recorded during the San Fernando earthquake of February 9, 1971. Characteristics of the principal components are investigated using the moving-window technique applied in both the time and frequency domains. A nonstationary random process is defined reflecting these same characteristics in a statistical sense. A computer program for generating principal directions and components of motion, wave-form characteristics, and sample accelerograms from the nonstationary random process is listed.

17. Key Words and Document Analysis. 17a. Descriptors

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages
	20. Security Class (This Page UNCLASSIFIED	

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ACKNOWLEDGMENT

The study presented herein is an extension of an investigation previously conducted by the authors in collaboration with Dr. M. Watabe, Mr. R. Iwasaki, and Mr. K. Ishida at the University of Tokyo. The authors are indebted to Mrs. Shirley Edwards for her excellence in typing the original manuscript. The financial support provided by the National Science Foundation under Grant No. GI-36387 is hereby acknowledged with sincere thanks and appreciation.

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I. INTRODUCTION

A. SCOPE OF INVESTIGATION

Up to the present time, most analytical investigations of the dynamic response of structural systems subjected to strong earthquake excitations have considered only one component of ground motion. It is becoming increasingly evident, however, that responses of some important structural systems such as three-dimensional piping systems, certain nuclear power plant components, highway bridge structures and earthfill dams are significantly affected by more than one component of earthquake motion. Fortunately, with the recent advances in techniques and facilities of high speed digital computers, it is becoming possible to conduct investigations of the dynamic response of such systems considering the multi-component influence of ground motion. Because of this awareness, there will obviously be an increasing demand in the future of dynamic response analyses of selected systems using multi-components of ground motion excitation.

Ground motion at a point O has six components, three translational and three rotational [36]*. While the three rotational components, two about horizontal axes (Rayleigh Waves) and one about a vertical axis (Love Waves), may influence overturing moments and torsional vibration of structural systems, it is usually sufficient to consider only the three translational components. Presently, the available earthquake accelerograms are not sufficient to permit an estimate of the rotational components.

A very simple approach to defining the three translational components of motion would be to assume that certain recorded ground

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*Numbers in square brackets refer to corresponding references.

motions of a part earthquake are representative of future site ground motions. This simple approach, however , is subject to question as two recorded accelerograms even at the same site location often have quite dissimilar characteristics.

Another approach is to generate accelerograms synthetically which have proper intensities and appropriate spectral densities. Recognizing that seismic waves are initiated by irregualr breaks and slippage along faults followed by numerous random reflections, refractions and attenuations within the complex ground formations through which they pass, stochastic modelling of strong ground motions is a realistic form for practical use. Defining earthquake inputs to a structural system in this manner has the distinct advantage that analyses yield mean values and variances of response consistent with the variations to be expected in ground motion characteristics.

Representive stochastic models for earthquake ground motion could be established directly by statistical analysis if unlimited data were available. Unfortunately, strong ground motion data in the form of accelerograms are quite limited. Therefore, one is forced to hypothesize model forms and to use the available strong ground motion data primarily in checking the appropriateness of these forms. A number of stochastic models, representing both stationary and nonstationary random processes, have been employed. Most of them, however, deal exclusively with only one translational component of motion [42,32]. One such model, commonly used in its one-dimensional form [23,37], defines ground accelerations at a point along three orthogonal axes (x, y and z), usually two horizontal and one vertical through the relations

$$
\begin{aligned}
a_x(t) &= \zeta_x(t)\ b_x(t) \\
a_y(t) &= \zeta_y(t)\ b_y(t) \\
a_z(t) &= \zeta_z(t)\ b_z(t)
\end{aligned}
\tag{1.1}
$$

where $b_x(t)$, $b_y(t)$ and $b_z(t)$ are stationary random processes and $\zeta_x(t)$, $\zeta_y(t)$ and $\zeta_z(t)$ are deterministic intensity functions giving an appropriate nonstationarity to their respective ground motion processes.

The use of Eqs. (1.1) requires that the appropriate intensity functions, $\zeta_x(t)$, $\zeta_y(t)$ and $\zeta_z(t)$ be obtained by statistical analyses of real accelerograms and that the realistic power spectral density functions, or corresponding auto-correlation functions, be established by similar means for processes $b_x(t)$, $b_y(t)$ and $b_z(t)$. When extending the use of this model to two- or three-dimensional form, the question immediately arises "Should the components of motions be cross correlated statistically?". If so, in addition to the power spectral density functions or corresponding auto-correlation functions, one must establish appropriate cross-spectral density functions or corresponding cross-correlation functions for processes $b_x(t)$, $b_y(t)$ and $b_z(t)$.

In this report, applying a procedure similar to the orthogonal transformation used in stress-state problems, an orthogonal set of principal axes is defined for three-dimensional earthquake ground motions. These principal axes are defined along which the components of ground motion have maximum, minimum and intermediate values of variances and have zero values of covariances. This property suggests that components of motions need not be cross correlated statistically provided they are directed along principal axes, i.e. provided the x, y and z axes in Eqs. (1.1) are treated as principal axes.

In this report, using the concept of an orthogonal set of principal axes and applying a moving-window technique to the accelerograms recorded during the San Fernando, California, earthquake of February 9, 1971, analyses of three-dimensional ground motions along principal axes are carried out. In these analyses, the time-dependent and the frequency-dependent characteristics of the principal values and the corresponding directions of principal axes of ground motions are determined and time-dependent characteristics of frequency content are examined through a moving-window fourier amplitude spectrum analysis.

It is concluded that realistic three components of ground motion can be generated stochastically using statistically uncorrelated nonstationary random processes along the prinicipal axes provided appropriate intensity functions and time-dependent frequency characteristics are used.

B. SAN FERNANDO EARTHQUAKE

The San Fernando, California, earthquake which occurred at 6:00:41.8 a.m. local time on February 9, 1971 has been assigned a location at 34° 24' 00" N and 118° 23' 42" W, a magnitude of 6.6 on the Richter scale and a depth of about 13 km. The epicenter of the earthquake has been located in the San Gabriel Mountains 14 km north of San Fernando, California. It has been reported that the fault slippage began at a depth of 13 km and progressed southward and upward at approximately 45°. A narrow band of surface faulting has been observed to run east-west in the foothills of the San Gabriel Mountains [3]. It has been reported that the faults slip zone spread to the south of epicenter [20] and the "energy center" was located approximately 3 km southwesterly of the epicenter [14]. The strong motion lasted about

12 seconds and a maximum intensity of XI has been assigned to the site of the Olive View Hospital located north of the Sylmar area [39].

As one can observe in Fig. 1.1, the local geological conditions around the fault slip zone are quite complex. This complexity is most likely the cause of weak correlations to exist between certain ground motion characteristics and the epicenter location as shown subsequently in this report.

C. STRONG GROUND MOTION ACCELEROGRAMS

The accelerograms used in this investigation were compiled and issued by the Earthquake Engineering Research Laboratory of the California Institute of Technology, Pasadena, in a report series entitled "STRONG MOTION EARTHQUAKE ACCELEROGRAMS: VOLUME II CORRECTED ACCELEROGRAMS AND INTEGRATED GROUND VELOCITY AND DISPLACEMENT CURVES" parts C through S [48]. Detailed information, such as directions of accelerometer axes and fundamental periods and damping ratios of transducers, are also available in these reports.

Corrections were applied to the recorded accelerograms using a procedure proposed by Trifunac [46,47,49,50]. In brief, the corrections were applied to the high and low frequency ranges in such a way that the resulting accelerograms would correspond to those recorded by accelerographs having the characteristics shown in Fig. 1.2. In the first stage of this procedure, the uncorrected accelerograms were passed through a Ormsby low-pass filter having a cut-off frequency and roll-off termination frequency of 25 cps and 27 cps respectively. In the second stage, a base-line correction was performed by passing the accelerograms through a high-pass filter having a cut-off frequency and roll-off termination frequency of 0.07 cps and 0.05 cps, respectively. In some cases, a cut-off frequency of 0.125 cps was used instead of 0.07 cps [17].

Hereafter in this report, accelerograph locations are identified using numbers given in "Annual List of Stations" issued by the Seismological Field Survey, NOS-NOAA [29]. The locations of accelerograph stations for which ground motions have been analyzed in this investigation are shown in Figs. 1.3, 1.4 and 1.5. Figure 1.3 shows the locations of stations in central and southern California. Figure 1.4 is an enlargement of the small rectangular area in Fig. 1.3 showing the extended Los Angeles and San Fernando region. Similarly, Fig. 1.5 is an enlargement of the small rectangular area in Fig. 1.4 showing the cities of Los Angeles, Hollywood and Beverly Hills. Table 1.1 summarizes station location, location coordinates for Figs, 1.3 - 1.5, approximate distances to the epicenter, directions to the epicenter, building structural types and general site geology for each station.

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29]

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
27	Grapevine Tehachapi Pumping Plant.	1 C-3	72.0	148	Small building.	15' of alluvium over gneiss (I)
52	Oso Pumping Plant.	2 B-1	53.5	147	Small building.	Alluvium (I)
96	Tejon	1 C-3	69.7	138	Small building.	Granitic (H)
102	Wheeler Ridge	1 C-2	87.3	142	Small building.	Alluvium 200'-300'. (S)
103	Anza	1 E-4	184.4	-59	Small building.	Alluvium (S)
104	Santa Anita Dam	2 D-4	42.1	-55	Small building.	Granite diorite complex. (H)
108	Carbon Canyon Dam	2 E-5	74.3	-43	Earthfill dam, height 99', crest length 2,610'.	Thin alluvium over poorly cemented siltstone. (I)

*see footnotes at end of table

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] -(CONTINUED)

STATION IDENTIFICATION NUMBER*I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( )*III
	SITE NAME	MAP*II KEY				
110	Castaic	2 B-2	29.5	126	Small building.	Sandstone (I)
113	Colton	1 D-3	106.5	-69	Small building.	Alluvium >500' (S)
114	Costa Mesa	2 E-6	94.5	-27	18-story RC*IV building	Terrace deposits (I)
121	Fairmont Reservoir	2 C-2	34.0	175		Granitic (H)
122	Glendale, 633 East Broadway	2 D-4	32.6	-25	3-story building	Alluvium (I)
123	Hemet	1 E-4	150.2	-60	Small building	Alluvium (S)
125	Lake Hughes, No. 1	2 C-2	30.9	172	Small building	Granitic (H)
126	Lake Hughes, No. 4	2 C-2	28.0	164	Small building	Weathered granitic (H)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
127	Lake Hughes, No. 9	2 B-2	27.7	147	Small building	Gneiss (H)
128	Lake Hughes, No. 12	2 B-2	24.4	142	Small building	Eocene sandstone below a shallow (10' ±) layer of alluvium (I)
130	Long Beach, Terminal Island	2 D-5	72.4	-12	Small building	Alluvium; water table at < 20' (S)
131	Long Beach, Utility Building	2 D-5	72.5	-15	3-story building	Alluvium; water table at 15' (S)
132	Long Beach, State College	2 D-5	74.1	-21	9-story building	Unconsolidated silt-sand-clay (S)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
133-5	Los Angeles, Hollywood Storage	3 C-1	35.7	-9	14-story RC building	700' ± of alluvium (S)
137-9	Los Angeles, Water and Power Building	3 F-2	41.1	-19	15-story St.*V building	Miocene siltstone (I)
140	Los Angeles, U.C.L.A.	3 A-2	37.4	8	7-story building	70' of alluvium over 5,000' of sedimentary rock (S)
141	Los Angeles, Griffith Park Observatory.	2 C-4	32.5	-16	Concrete pier on bedrock	Granitic (H)
142-4	Los Angeles, 120 Robertson	3 B-2	36.1	-2	9-story RC building	Alluvium (S)
145-7	Los Angeles, 222 South Figueroa.	3 E-2	40.4	-19	17-story RC building	25' of alluvium over shale; water table at 20'. (I)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
148-50	Los Angeles, 234 South Figueroa.	3 E-2	40.4	-18	17-story RC building	25' of alluvium over shale; water table at 20'. (I)
151-3	Los Angeles, 250 East First	3 F-2	41.4	-20	15-story St. building	Alluvium (S)
154-6	Los Angeles, 420 South Grand.	3 E-2	41.1	-19	16-story St. building	Shale and silt-stone several 1,000'. ( )
157-9	Los Angeles, 445 South Figueroa.	3 E-2	40.6	-18	39-story St. building	Shale (S)
160-2	Los Angeles, 533 South Fremont.	3 E-2	40.6	-18	10-story RC building.	Alluvium (S)
163-5	Los Angeles, 611 West Sixth.	3 E-3	41.1	-18	43-story St. building	Alluvium (S)
166-8	Los Angeles, 646 South Olive.	3 E-3	41.3	-18	8-level RC parking ramp.	Alluvium (S)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
172-4	Los Angeles, 800 West First.	3 E-2	40.4	-19	31-story St. building.	Pliocene siltstone. (I)
175-7	Los Angeles, 808 South Olive.	3 E-3	42.7	-18	8-level RC parking ramp.	Alluvium (S)
181-3	Los Angeles, 1640 Marengo.	2 D-4	41.3	-24	7-story RC building.	Pleistocene alluvium; water table at 35'. (S)
184-6	Los Angeles, 1900 Avenue of Stars.	3 B-2	37.9	3	27-story St. building.	Silt and sand layers; water level at 70'. (S)
187-9	Los Angeles, 1901 Avenue of Stars.	3 B-2	38.5	3	19-story St. building.	Silt and sand layers; water table at 70'-80'. (S)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
190-2	Los Angeles, 2011 Zonal.	2 D-4	41.7	-25	9-story RC building.	Shale at east end of building; 8' of fill at west end (I)
196-8	Los Angeles, 3345 Wilshire.	3 D-2	38.6	-14	12-story RC building.	Alluvium (S)
199-201	Los Angeles, 3407 West Sixth.	3 D-2	38.6	-14	7 stories; 2 St. and 5 RC	Alluvium (S)
202-4	Los Angeles, 3411 Wilshire.	3 D-2	38.5	-13	31-story St. building.	Siltstone; water table at basement level. (I)
205-7	Los Angeles, 3440 University, U.S.C.	3 E-3	43.2	-14	12-story RC building.	400' of alluvium over clay and shale; water table at 275'. (S)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
208-10	Los Angeles, 3470 Wilshire.	3 D-2	38.7	-13	11-story RC building.	Alluvium (S)
211-3	Los Angeles, 3550 Wilshire.	3 D-2	38.6	-13	21-story St. building.	Alluvium; water table at 35'. (S)
217-9	Los Angeles, 3710 Wilshire.	3 D-2	38.5	-12	11-story RC building.	Alluvium (I)
220-2	Los Angeles, 3838 Lanker-shim.	2 C-4	29.4	-6	20-story RC building.	Interlayered soft sand-stone and shale. (I)
223-5	Los Angeles, 4680 Wilshire.	3 D-2	38.1	-9	7-story RC building.	Alluvium (I)
226-8	Los Angeles, 4867 Sunset.	3 D-1	34.8	-16	8-story RC building.	Shallow alluvium over Miocene silt-stone. (I)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
229-31	Los Angeles 5260 Century.	2 C-5	50.6	-2	7-story St. building.	Alluvium (S)
232-4	Los Angeles, 6430 Sunset.	3 D-1	34.2	-10	14-story St. building.	Alluvium; water table at 55'. (S)
235-7	Los Angeles, 6464 Sunset.	3 D-1	34.2	-10	11-story St. building.	Alluvium; water table at 55'. (S)
238-40	Los Angeles, 7080 Hollywood.	3 C-1	33.5	-8	11-story RC building.	Alluvium (S)
241-3	Los Angeles, 8244 Orion.	2 C-4	21.1	19	7-story RC building.	Alluvium (S)
244-6	Los Angeles, 8639 Lincoln.	2 C-5	49.0	3	12-story RC building.	Terrace deposits-- sand. (S)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
247-9	Los Angeles 9841 Airport Boulevard.	2 C-5	50.5	-1	14-story RC building.	Alluvium (S)
253-5	Los Angeles, 14724 Ventura.	2 C-4	28.1	11	12-story RC building.	Alluvium (S)
262	Palmdale	2 D-2	32.6	-127	Small building.	Alluvium (S)
264-5	Pasadena, Millikan Library, C.I.T.	2 D-4	38.4	-40	9-story RC building.	Approximately 1,000' of alluvium upon granite. (S)
266	Pasadena, Seismo-logical Laboratory.	2 D-4	34.7	-36	2-story building.	Weathered granitic. (H)
267-8	Pasadena, Jet Pro-pulsion Laboratory.	2 D-4	30.1	-42	9-story St. building.	Sandy-gravel. (I)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
269	Pearblossom	2 E-2	45.0	-106	Small building.	400' of alluvium over 14,000' of sedimentary rock. (S)
272	Port Hueneme.	1 B-3	79.0	69	Small building.	Alluvium, > 1,000'. (S)
274	San Bernardino.	1 D-3	107.2	-72	6-story building.	Alluvium, 1,000'; water table at 30'. (S)
278	Puddingstone Dam.	2 E-4	63.7	-57	Small building.	Volcanic clastics and intrusions with associated shales. (H)
279	Pacoima Dam.	2 C-3	7.2	1	Small building.	Highly jointed diorite gneiss. (H)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
280	San Onofre	1 D-4	138.6	-34	Small building.	Lightly cemented Pliocene sandstone > 325' depth. (I)
281	Santa Ana	2 E-5	87.1	-34	3-story building.	Alluvium (S)
282	Santa Barbara, University of California.	1 B-3	133.5	90	2-story building.	Alluvium veneer over sandstone. (I)
284-5	Santa Felicia Dam.	2 A-3	33.3	102	Earthfill dam; height 200', crest length 1,260'.	Sandstone-shale complex. (I)
287	San Antonio Dam.	2 F-4	71.1	-68	Earthfill dam; height 160', crest length 3,850'.	Up to 150' of alluvium over granitics. (S)
288	Vernon	2 D-4	48.0	-22	6-story building.	> 1,000' of alluvium; water table at > 300'. (S)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
289	Whittier Narrows Dam.	2 D-4	52.7	-37	Earthfill dam; height 56'. crest length 14,960'.	More than 1,000' of alluvium. (S)
290	Wrightwood	2 F-3	70.1	-86	Small building.	Alluvium veneer on igneous metamorphic complex. (I)
292-4	Hoover Dam, Nev.	1 G-1	378.1	-118	Concrete dam.	Several 100' of volcanic breccia over basalt. (H)
411	Palos Verdes Estates.	2 C-5	66.7	-1	2-story building.	Shallow Pleistocene sands over shale-volcanic complex. (I)
413-5	Los Angeles, 1177 Beverly Drive.	3 B-2	38.3	0	Arcuate-shaped 7-story RC building.	Alluvium (S)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
416-8	Beverly Hills, 9100 Wilshire.	3 B-2	37.1	-1	10-story RC building.	Alluvium; water table at 40'. (S)
425-7	Los Angeles, 1800 Century Park East.	3 B-2	37.5	3	15-story RC building.	Silt and sand layers; water table at 70'-80'. (S)
428-30	Los Angeles, 5900 Wilshire.	3 C-2	37.7	-5	31-story St. building.	Alluvium-- asphaltic sands. (I)
431-3	Los Angeles, 616 South Normandie.	3 D-2	38.6	-13	16-story RC building.	Alluvium, siltstone at 25'. (I)
437-9	Los Angeles 1150 South Hill.	3 E-3	41.5	-17	10-story St. building.	500' of gravelly sand over shale. (S)
440-2	Los Angeles, 1880 Century Park East.	3 B-2	37.6	3	16-story St. building.	Silt and sand layers; water table at 70'-80'. (S)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
443-5	Los Angeles, 6200 Wilshire.	3 C-2	37.6	-5	17-story RC building.	Thin layer of alluvium over asphaltic sands. (I)
446-8	Los Angeles, 1760 North Orchid.	3 C-1	33.4	-9	22-story RC building.	Alluvium (S)
449-51	Los Angeles, 2500 Wilshire.	3 E-2	39.3	-16	13-story RC building.	Alluvium; siltstone at 20'-30'; and water table at 35'. (I)
452-4	Beverly Hills, 435 North Oakhurst.	3 B-2	35.8	-1	10-story RC building.	Alluvium; water table at 22'. (S)
455-7	Beverly Hills, 450 North Roxbury.	3 B-2	36.9	2	10-story RC building.	Alluvium (S)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
458-60	Los Angeles, 15107 Vanowen.	2 C-4	33.5	-47	Circular 7-story RC building.	Alluvium 500'; water table at 70'. (S)
461-3	Los Angeles, 15910 Ventura.	2 C-4	27.8	16	17-story St. building.	Alluvium; water table at 35'. (S)
465	San Juan Capistrano.	2 F-7	121.3	-33	Small building.	Alluvium (S)
466-8	Los Angeles, 15250 Ventura.	2 C-4	28.1	13	12-story RC building.	Alluvium; water table at 55'. (S)
469-71	Los Angeles, 1625 Olympic.	3 E-3	40.5	-16	10-story RC building.	Alluvium (S)
472-4	Orange, 4000 West Chapman.	2 E-5	83.0	-34	19-story RC building.	Alluvium > 300' over shale. (S)

TABLE 1.1 ACCELEROGRAPH SITE INFORMATION [29] - (CONTINUED)

STATION IDENTIFICATION NUMBER *I	STATION LOCATION		APPROXIMATE DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER (DEGREE)	BUILDING STRUCTURAL TYPE	SITE GEOLOGY ( ) *III
	SITE NAME	MAP *II KEY				
475	Pasadena, C.I.T. Athenaeum.	2 D-4	38.4	-41	2-story building.	Approximately 1,000' of alluvium upon granite. (S)
476-78	Fullerton, 2600 Nutwood.	2 E-5	108.8	-58	10-story RC building.	Alluvium (S)
482-4	Alhambra, 900 South Fremont.	2 D-4	41.7	-33	12-story St. building.	Few 100' of alluvium over siltstone. (S)

*I Permanent Identification number in annual list of stations issued by the Seismological Field Servey, NOS-NOAA.

*II Map numbers 1, 2 and 3 correspond to Figs. 1.3, 1.4 and 1.5, respectively.

*III ( ) represents an abbreviated site classification. (S), (I) and (H) correspond to soft, intermediate and hard site classifications, respectively [51].

*IV RC = reinforced concrete.

*V St. = steel.

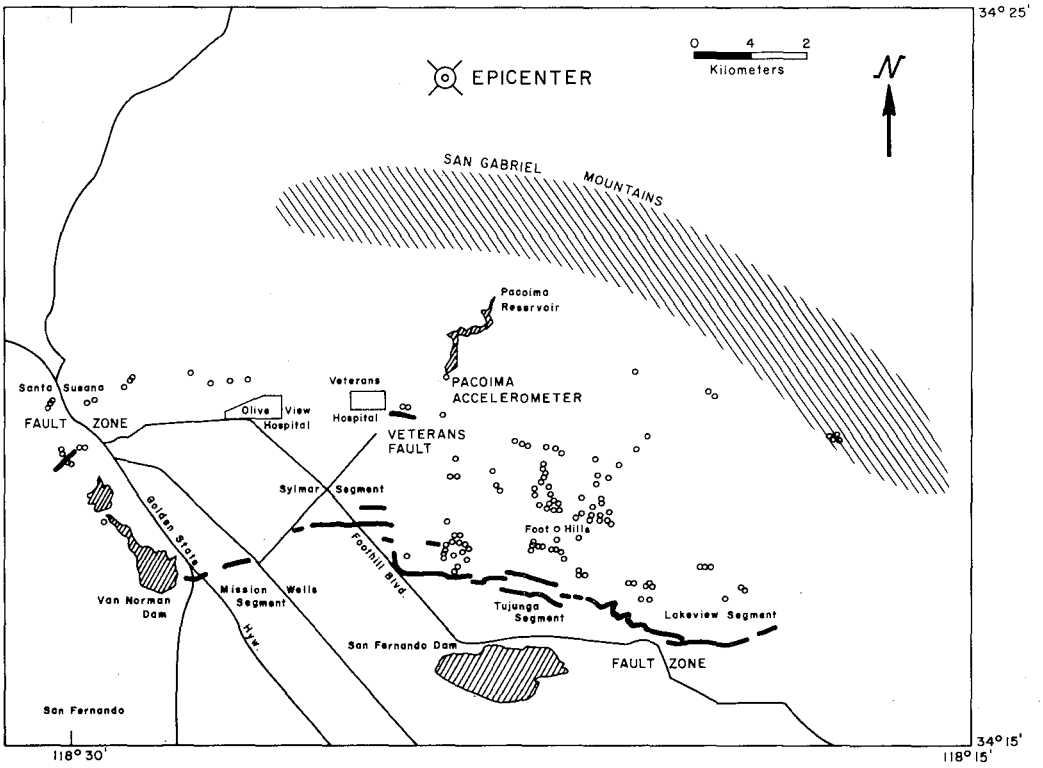


Fig. 1.1 Map of surface fault traces, San Fernando earthquake. [3]

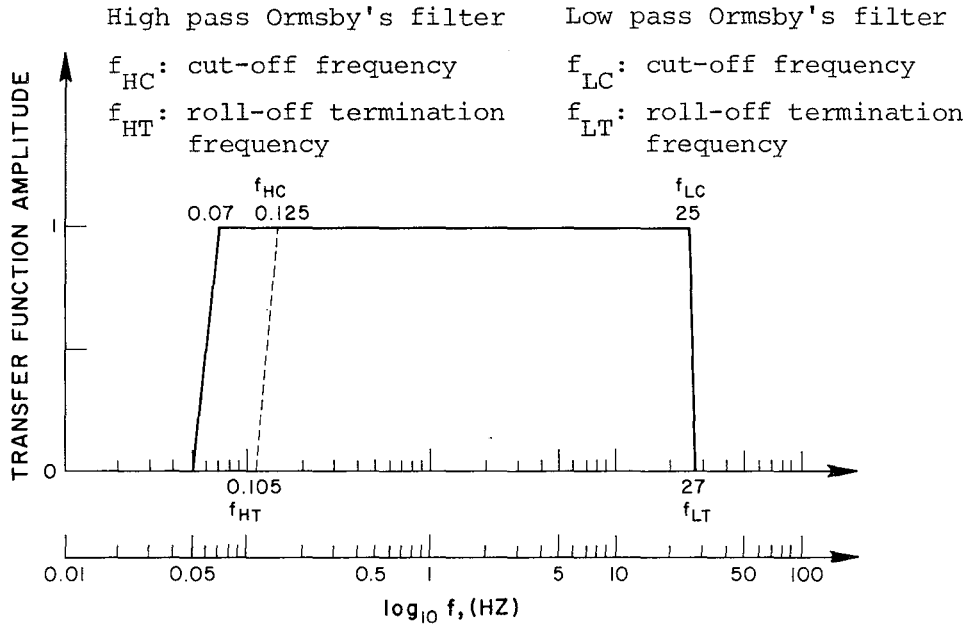


Fig. 1.2 Transfer function for instrument and baseline corrections of strong motion accelerograms.

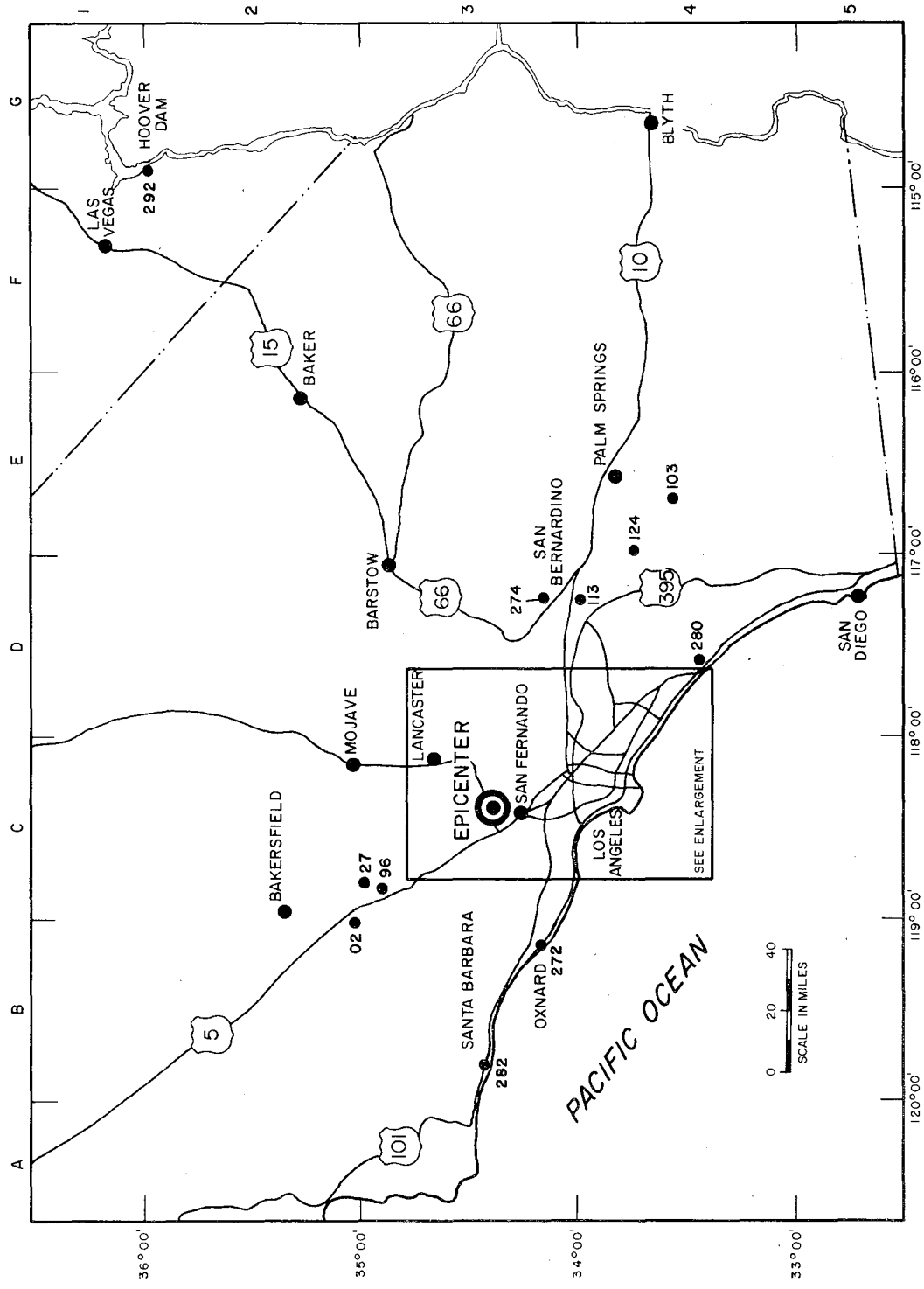


Fig. 1.3 Accelerograph site locations in central and southern California.

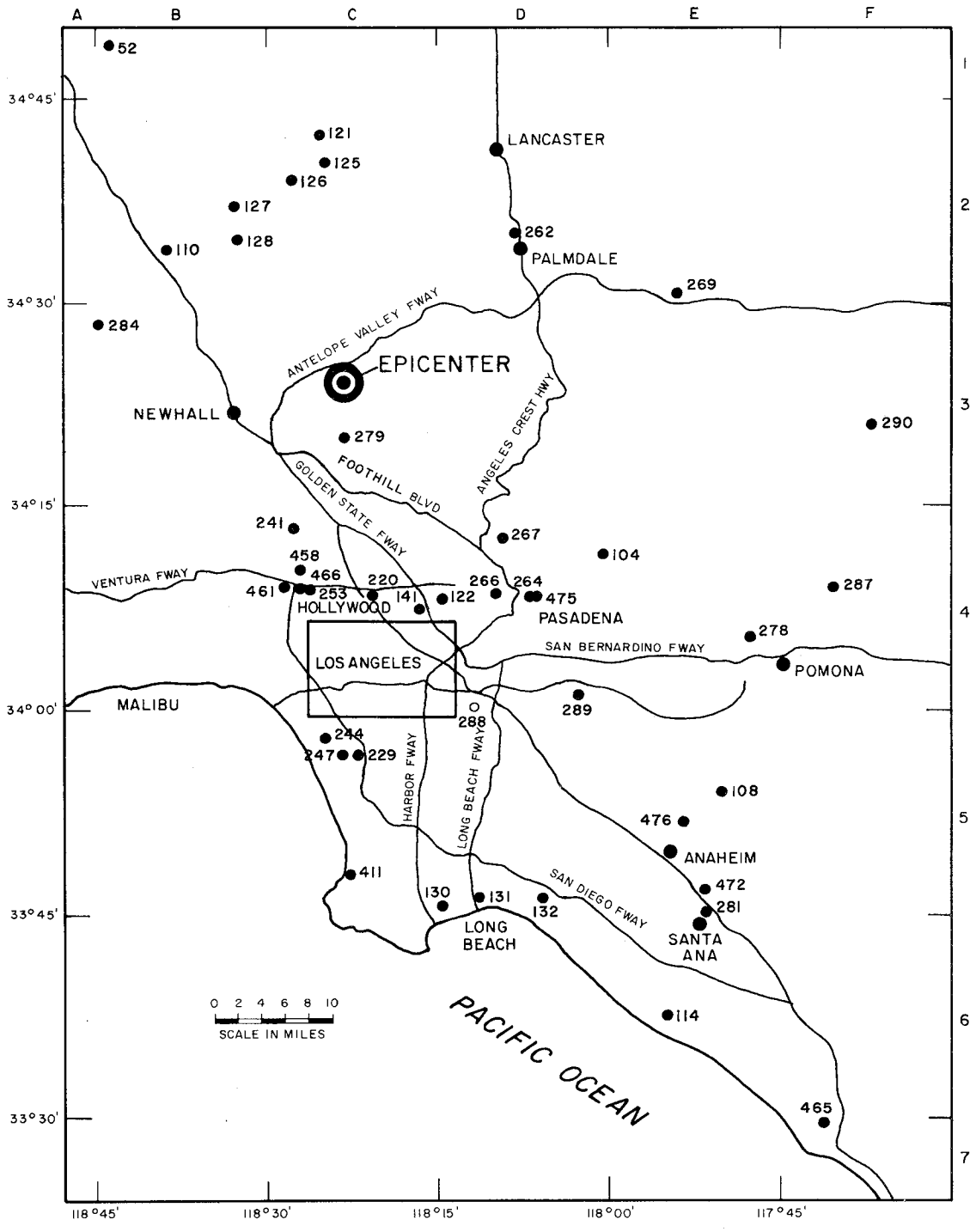


Fig. 1.4 Accelerograph site locations in extended Los Angeles area.

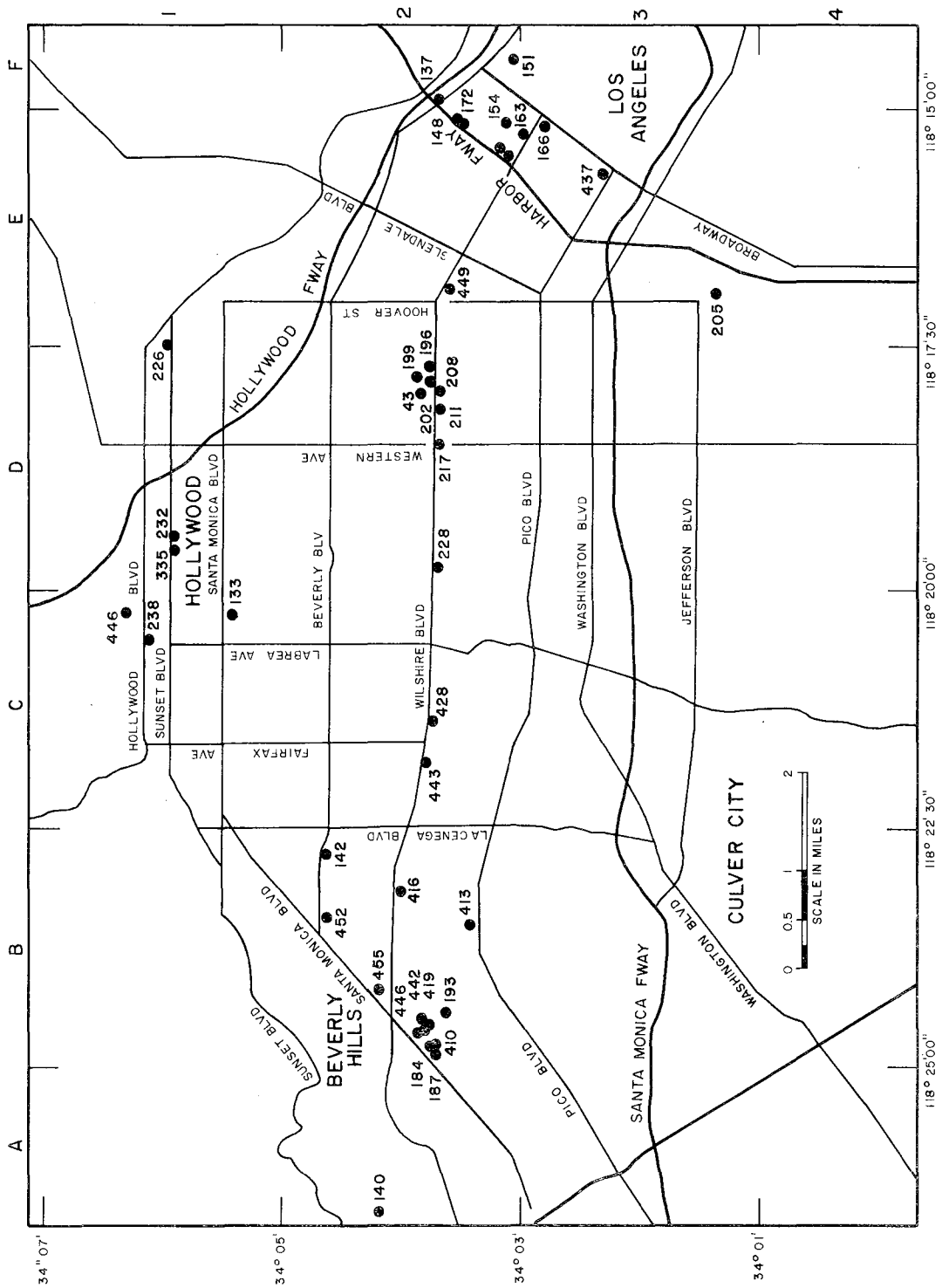


Fig. 1.5 Accelerograph site locations in central Los Angeles.

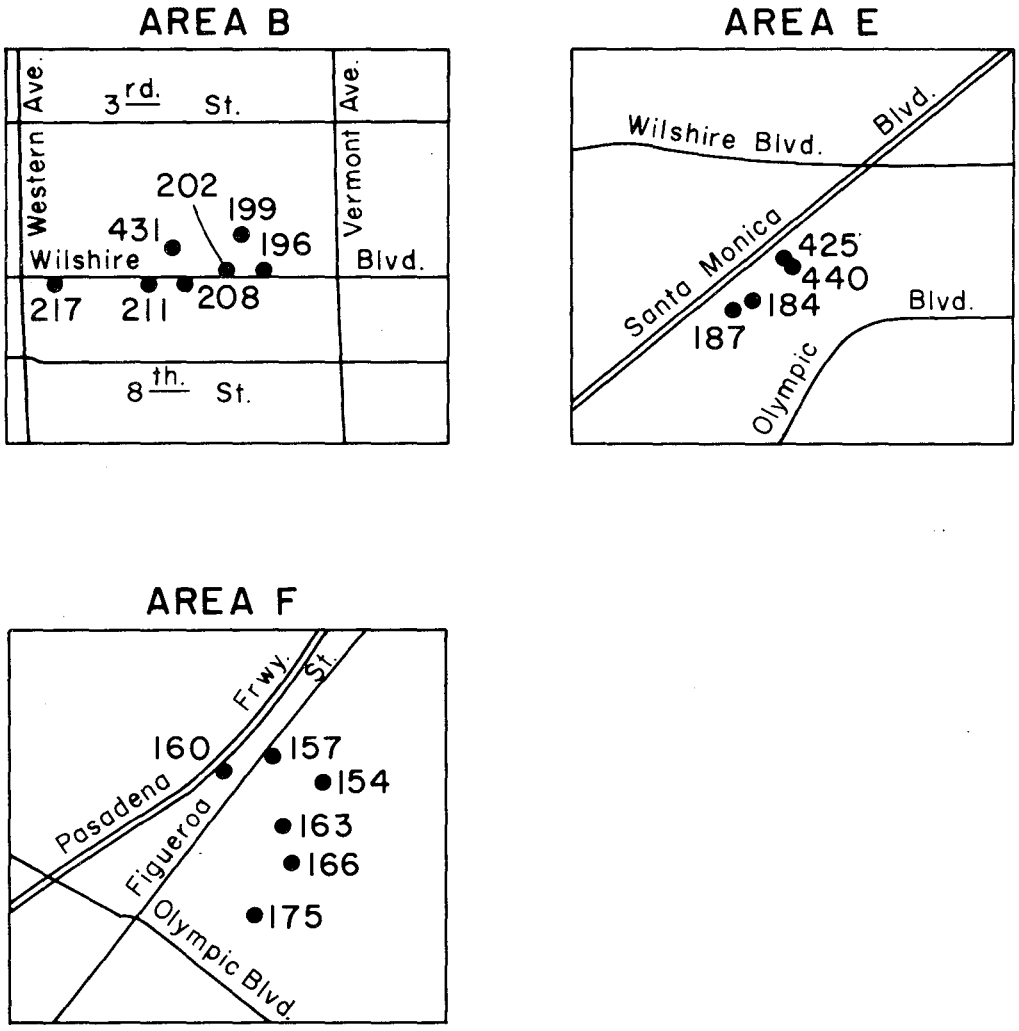


Fig. 1.6 Accelerograph site locations along Wilshire Boulevard, Santa Monica Boulevard and Figueroa Street.

II. PRINCIPAL AXES FOR GROUND MOTION

A. FIXED PRINCIPAL AXES

Suppose three components of ground motion, $a_x(t)$, $a_y(t)$ and $a_z(t)$ at a point 0 along an arbitrary set of orthogonal axes x, y and z are defined through the following stochastic model

$$\begin{aligned} a_x(t) &= \zeta(t)\, b'_x(t) \\ a_y(t) &= \zeta(t)\, b'_y(t) \\ a_z(t) &= \zeta(t)\, b'_z(t) \end{aligned} \tag{2.1}$$

where $b'_x(t)$, $b'_y(t)$ and $b'_z(t)$ are stationary random processes and $\zeta(t)$ is a deterministic intensity function. This model represents an approximation to that defined by Eqs. (1.1). In this model, it is assumed that the intensity functions in the three directions vary with time in identically the same manner even though they may differ by a scalar factor. Considering recorded earthquake motion, these components normally represent accelerations measured along the instrument axes of accelerometers. For the purpose of discussion here, however, these components could equally well represent velocities or displacements.

If $a_x(t)$, $a_y(t)$ and $a_z(t)$ of Eqs. (2.1) are considered to be zero-mean process, covariance functions defined by

$$E\,[a_i(t)\, a_j(t+\tau)] = \zeta(t)\, \zeta(t+\tau)\, E\,[b'_i(t)\, b'_j(t+\tau)] \qquad i,j = x,y,z \tag{2.2}$$

where E denotes ensemble averages, can be used to characterize the complete ground motion process. If this process is Gaussian, these covariance functions completely characterize the process in a probabilistic sense [5].

Since random processes $b'_x(t)$, $b'_y(t)$ and $b'_z(t)$ are stationary, all ensemble averages on the right hand side of Eqs. (2.2) are independent of time t; therefore, showing dependence only upon the time difference τ. Since in the first approximation, real earthquake accelerograms can be represented by white noise [19,10,35], these processes demonstrate a very rapid loss in correlation with increasing values of $|\tau|$. Therefore, the influence of coordinate directions on covariance functions can be investigated using the approximate relations

$$E\,[a_i(t)\ a_j(t)] = \zeta^2(t)\ E\,[b'_i(t)\ b'_j(t)] \qquad (2.3)$$
$$i,j = x,y,z$$

Adopting matrix notation, Eqs. (2.3) can be written in the more compact form

$$\underline{\mu}(t) = \zeta^2(t)\ \underline{\beta} \qquad (2.4)$$

where

$$\mu_{ij}(t) = E\,[a_i(t)\ a_j(t)] \qquad (2.5)$$

$$\beta_{ij} = E\,[b'_i(t)\ b'_j(t)] \qquad (2.6)$$
$$i,j = x,y,z$$

Note that because random processes $b'_x(t)$, $b'_y(t)$ and $b'_z(t)$ are stationary, all nine coefficients in matrix $\underline{\beta}$ are time invariant.

If the components of ground motion at point 0 are transformed from coordinate system x,y and z to a new orthogonal coordinate system x',y' and z' through the relation

$$\begin{Bmatrix} a'_x(t) \\ a'_y(t) \\ a'_z(t) \end{Bmatrix} = \underline{A} \begin{Bmatrix} a_x(t) \\ a_y(t) \\ a_z(t) \end{Bmatrix} \qquad (2.7)$$

where the transformation matrix $\underline{A}$ satisfies the condition

$$\underline{A}^T \underline{A} = \underline{I} \quad \text{(identity matrix)} \tag{2.8}$$

relations identical to Eqs. (2.4) - (2.6) can be written for the new coordinate system with

$$\underline{\beta}' = \underline{A}^T \underline{\beta} \underline{A} \tag{2.9}$$

$$\underline{\mu}' = \underline{A}^T \underline{\mu} \underline{A}$$

$$= \zeta^2(t) \underline{A}^T \underline{\beta} \underline{A} \tag{2.10}$$

This transformation of ground motion is quite identical to the transformation of a three-dimensional state of stress; therefore, it is apparent that a set of principal axes exist along which the component variances of motion have maximum, minimum and intermediate values and the corresponding covariances have zero values. The directions of these principal axes are found in exactly the same manner as locating the directions of principal stresses, i.e. by obtaining the eigenvalue formulation. The resulting three vectors define the principal transformation matrix $\underline{P}$; thus, permitting the components of ground motion along principal axes, 1, 2 and 3 to be given by

$$\begin{Bmatrix} a_1(t) \\ a_2(t) \\ a_3(t) \end{Bmatrix} = \underline{P} \begin{Bmatrix} a_x(t) \\ a_y(t) \\ a_z(t) \end{Bmatrix} \tag{2.11}$$

where

$$\underline{P}^T \underline{P} = \underline{I} \tag{2.12}$$

The corresponding covariance matrix for ground motion becomes

$$\begin{aligned}
\underline{\mu}_p(t) &= \underline{P}^T \underline{\mu}(t) \underline{P} \\
&= \zeta^2(t) \underline{p}^T \underline{\beta} \underline{P} \\
&= \zeta^2(t) \begin{bmatrix} \beta_{11} & 0 & 0 \\ 0 & \beta_{22} & 0 \\ 0 & 0 & \beta_{33} \end{bmatrix} \\
&= \begin{bmatrix} \mu_{11} & 0 & 0 \\ 0 & \mu_{22} & 0 \\ 0 & 0 & \mu_{33} \end{bmatrix}
\end{aligned} \tag{2.13}$$

The principal values are given by $\zeta^2(t)\ \beta_{11}$, $\zeta^2(t)\ \beta_{22}$ and $\zeta^2(t)\ \beta_{33}$ and the directions of principal axes are given by the corresponding column vectors of the transformation matrix $\underline{P}$, respectively. Since the covariance matrix $\underline{\beta}$ in Eqs. (2.13) is time invariant, the coefficients of the principal transformation matrix $\underline{P}$ are also time invariant; that is, the directions of principal axes are fixed during the entire time history of motion.

Fortunately for most physical phenomena represented by random processes, the desired properties can often be estimated using a single member from each process. This is, of course, strictly true only for ergodic random processes. Therefore, the covariances in Eqs. (2.13) can be obtained by time averaging over any single member of the process, say the rth member. In this case, β_{ij} defined by Eqs. (2.6) can be obtained through the relation

$$\beta_{ij} = < b'_{ir}(t)\ b'_{jr}(t) > \tag{2.14}$$

$$i,j = x,y,z$$

$$r = 1,2,3,....$$

where the triangular brackets denote time average.

To further illustrate the physical meaning of principal axes, consider two stationary random processes $x_1(t)$ and $x_2(t)$. The auto- and cross-correlation functions of these processes are given by

$$R_{ij}(\tau) = E\,[x_i(t)\; x_j(t+\tau)] \qquad i,j = 1,2 \tag{2.15}$$

where E denotes the ensemble averages. These functions can be decomposed and expressed in the frequency domain by the equivalent relation

$$S_{ij}(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} R_{ij}(\tau)\; e^{-i\omega\tau}\, d\tau \tag{2.16}$$

and

$$R_{ij}(\tau) = \int_{-\infty}^{\infty} S_{ij}(\omega)\; e^{+i\omega t}\, d\omega \qquad i,j = 1,2 \tag{2.17}$$

These relations which express $R_{ij}(\tau)$ and $S_{ij}(\omega)$ as Fourier transform pairs are usually called the Wiener-Khintchine relations.

Suppose random processes $x_1(t)$ and $x_2(t)$ are considered to be ergodic processes in which case ensemble averages are equivalent to the corresponding time averages i.e.

$$E\,[x] = \langle x_r \rangle \tag{2.18}$$

where subscript r denote r^{th} member of ensemble x. Relations between ensemble averages and temporal averages which are respectively designated by $R_{ij}(\tau)$ and $\Phi_{ij}(\tau)$ $(i,j = 1,2)$ and those between their corresponding

quantities decomposed into the frequency domain $S_{ij}(\omega)$ and $G_{ij}(\omega)$ $(i,j = 1,2)$ are obtained by Eqs. (2.15) - (2.18),

$$\begin{aligned} R_{ij}(\tau) &= E\,[x_i(t)\; x_j(t+\tau)] \\ &= \langle x_{ir}(t)\; x_{jr}(t+\tau) \rangle \\ &= \Phi_{ij}(\tau) \end{aligned} \tag{2.19}$$

$$\begin{aligned} S_{ij}(\omega) &= \frac{1}{2\pi} \int_{-\infty}^{\infty} R_{ij}(\tau)\; e^{-i\omega\tau}\, d\tau \\ &= \frac{1}{2\pi} \int_{-\infty}^{\infty} \Phi_{ij}(\tau)\; e^{-i\omega\tau}\, d\tau \\ &= G_{ij}(\omega) \\ & \quad i,j = 1,2 \end{aligned} \tag{2.20}$$

Principal axes were defined previously along which the components of motion have maximum and minimum values of variances and have zero values of covariances for $\tau = 0$. Intensities of the process along principal axes can be evaluated by subsituting $\tau = 0$ into Eqs. (2.15) - (2.20). It follows that

$$\begin{aligned} \Phi_{ij}(0) &= \lim_{T\to\infty} \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} x_i(t)\; x_j(t)\, dt \\ &= \int_{-\infty}^{\infty} G_{ij}(\omega)\, d\omega \\ &= \begin{cases} G & (\text{if } i = j) \\ 0 & (\text{if } i \neq j) \end{cases} \\ & \quad i,j = 1,2 \end{aligned} \tag{2.21}$$

These properties reveal that components of motion along principal axes have maximum and minimum values of power [2] and zero values of cross power. Note that cross-correlation function $R_{12}(\tau)$ and $R_{21}(\tau)$ are not generally even functions; therefore, unlike the power spectral density functions $G_{11}(\omega)$ and $G_{22}(\omega)$ which are always real and positive, the cross-power spectral density functions $G_{12}(\omega)$ and $G_{21}(\omega)$ are generally complex. Note also that for principal axes the cross-power $\int_{-\infty}^{\infty} G_{12}(\omega)\, d\omega$ and $\int_{-\infty}^{\infty} G_{21}(\omega)\, d\omega$ are zero, even though the functions $G_{12}(\omega)$ and $G_{21}(\omega)$ may not be zero.

It can be concluded, however, that for a first approximation to modelling of ground motions, it is sufficient to accept the concept of principal axes which do not require one to establish cross powers between the individual components of motion.

B. TIME DEPENDENT PRINCIPAL AXES

It is easily shown that the intensity functions along an orthogonal set of axes, x, y and z (usually taken as instrumental axes), do not have the same identical shape. For example, observe the shapes of the intensity functions (sigma vs. time) in Figs. 2.2a through 2.2d for the three components of motion along the instrumental axes at stations Nos. 266, 475, 264 and 267; see Fig. 1.4 for location. These intensity functions are defined through the relation [22]

$$\zeta_i(t_o, \Delta T) = \sqrt{\frac{1}{\Delta T} \int_{t_o - \frac{\Delta T}{2}}^{t_o + \frac{\Delta T}{2}} a_i^2(t)\, dt} \qquad (2.22)$$

$$i = x,y,z$$

with $\Delta t = 5$ seconds. The solid, intermediate-dashed and short-dashed curves represent the components of motion along the north-south,

east-west and vertical axes, respectively. The upper set of curves in these figures (theta and phi vs. time) represent the angles shown in Fig. 2.1. The intermediate-dashed curve represents θ (degree) corresponding to the left side coordinate of the axis and the short-dashed curve represents ϕ (degree) corresponding to the right side coordinate of the axis. If the intensity functions $\zeta_x(t)$, $\zeta_y(t)$ and $\zeta_z(t)$ are identically the same in magnitude, angles θ and ϕ are 45° ($\tan^{-1} 1$) and 54.7° ($\cos^{-1} \frac{1}{\sqrt{3}}$), respectively. Further, if the intensity functions vary with time in identically the same manner even though they may have different magnitudes, i.e. satisfy Eqs. (2.1), the values of θ and ϕ are invariant with time. In this case, the curves representing angles θ and ϕ become straight horizontal lines. As one can see in Figs. 2.2, the intensity functions for actual strong ground motions do not change with time in the same manner, i.e. the directions of the principal axes are not time invariant.

Suppose the three components of ground motion are represented by the relations

$$\begin{aligned} a_x(t) &= \zeta_x(t)\, b_x(t) \\ a_y(t) &= \zeta_y(t)\, b_y(t) \\ a_z(t) &= \zeta_z(t)\, b_z(t) \end{aligned} \tag{2.23}$$

where $b_x(t)$, $b_y(t)$ and $b_z(t)$ are stationary random processes and $\zeta_x(t)$, $\zeta_y(t)$ and $\zeta_z(t)$ are dissimilar deterministic functions along the x, y and z axes, respectively. Assuming $a_x(t)$, $a_y(t)$ and $a_z(t)$ to be zero mean processes and applying the procedures previously described, covariance functions are defined by

$$E\,[a_i(t)\ a_j(t+\tau)] = \zeta_i(t)\ \zeta_j(t+\tau)\ E\,[b_i(t)\ b_j(t+\tau)] \qquad (2.24)$$

$$i,\ j = x,y,z$$

These covariance functions for a zero value of the time difference τ, can be written in the matrix form

$$\underline{\mu}(t) = \underline{\zeta}(t)\ \underline{\beta}\ \underline{\zeta}(t) \qquad (2.25)$$

where

$$\mu_{ij}(t) = E\,[a_i(t)\ a_j(t)] \qquad (2.26)$$

$$\beta_{ij} = E\,[b_i(t)\ b_j(t)] \qquad (2.27)$$

$$\zeta_{ij}(t) = \begin{cases} \zeta_i(t) & (i = j) \\ 0 & (i \neq j) \end{cases} \qquad (2.28)$$

$$i,\ j = x,y,z$$

Applying an orthogonal transformation identically similar to the one previously described, the covariance functions along the principal axes become

$$\begin{aligned} \underline{\mu}_p &= \underline{P}^T\ \underline{\mu}(t)\ \underline{P} \\ &= \underline{P}^T\ \underline{\zeta}(t)\ \underline{\beta}\ \underline{\zeta}(t)\ \underline{P} \\ &= (\underline{\zeta}(t)\ \underline{P})^T\ \underline{\beta}\ (\underline{\zeta}(t)\ \underline{P}) \\ &= \begin{bmatrix} \mu_{11} & 0 & 0 \\ 0 & \mu_{22} & 0 \\ 0 & 0 & \mu_{33} \end{bmatrix} \end{aligned} \qquad (2.29)$$

Note that because the intensity matrix $\underline{\zeta}(t)$ is a diagonal matrix, $\underline{\zeta}^T_{(t)}$ is equal to $\underline{\zeta}(t)$.

In Eqs. (2.29), the principal transformation matrix $\underline{P}$ is given as a function of time t, i.e. $\underline{P} = \underline{P}(t)$. Since the column vectors of the principal transformation matrix give the direction cosines of the corresponding principal axes, the directions of the principal axes are time-dependent when the three components of motion are defined in accordance with Eqs. (2.23).

C. MAXIMUM VARIANCES AND COVARIANCES

If one assumes each component of motion to be identically the same, the direction of the instantaneous resultant acceleration vector will not change in time; thus, the components will be completely correlated, i.e. the cross correlation coefficients obtained from the relation

$$\rho_{ij} = \frac{E[a_i(t)\ a_j(t)]}{\sqrt{E[a_i(t)\ a_i(t)]\ E[a_j(t)\ a_j(t)]}} \qquad (2.30)$$

$$i \neq j$$

will be equal to either +1 or -1 depending upon the pair of components involved. On the other hand, if the components are actual recorded ground motions, the cross correlation coefficients will be greatly reduced showing lack of correlation with each other. Note that a cross correlation coefficient equal to zero, indicates a complete lack of correlation.

It is interesting to investigate the characteristics of motion along sets of axes which give maximum correlated components of motion as well as along the principal axes which give completely uncorrelated components of motion. A procedure similar to that previously described can be used to determine the coordinate transformations which yield

maximum covariances. When transforming from principal axes 1, 2 and 3, this procedure leads to the following orthogonal transformation matrices

$$\underline{S}_1 = \begin{bmatrix} \pm 1 & 0 & 0 \\ 0 & \pm\sqrt{\frac{1}{2}} & \pm\sqrt{\frac{1}{2}} \\ 0 & \mp\sqrt{\frac{1}{2}} & \pm\sqrt{\frac{1}{2}} \end{bmatrix}$$

$$\underline{S}_2 = \begin{bmatrix} \pm\sqrt{\frac{1}{2}} & 0 & \pm\sqrt{\frac{1}{2}} \\ 0 & \pm 1 & 0 \\ \mp\sqrt{\frac{1}{2}} & 0 & \pm\sqrt{\frac{1}{2}} \end{bmatrix} \qquad (2.31)$$

$$\underline{S}_3 = \begin{bmatrix} \pm\sqrt{\frac{1}{2}} & \pm\sqrt{\frac{1}{2}} & 0 \\ \mp\sqrt{\frac{1}{2}} & \pm\sqrt{\frac{1}{2}} & 0 \\ 0 & 0 & \pm 1 \end{bmatrix}$$

Substituting Eqs. (2.31) separately into the relation

$$\underline{\mu}_{Cm}(t) = \underline{S}_m^T \; \underline{\mu}_P(t) \; \underline{S}_m \qquad (2.32)$$

$$m = 1, 2, 3$$

gives principal covariances equal to $\frac{1}{2}[\mu_{22}(t) - \mu_{33}(t)]$, $\frac{1}{2}[\mu_{11}(t) - \mu_{33}(t)]$ and $\frac{1}{2}[\mu_{11}(t) - \mu_{22}(t)]$. The corresponding variances are $\mu_{11}(t)$, $\mu_{22}(t)$ and $\mu_{33}(t)$, and the corresponding mean variances are $\frac{1}{2}[\mu_{22}(t) + \mu_{33}(t)]$, $\frac{1}{2}[\mu_{11}(t) + \mu_{33}(t)]$ and $\frac{1}{2}[\mu_{11}(t) + \mu_{22}(t)]$, respectively. Using these values, the principal

cross correlation coefficients are given by

$$\rho_{12} = \frac{[\mu_{11}(t) - \mu_{22}(t)]}{[\mu_{11}(t) + \mu_{22}(t)]}$$

$$\rho_{23} = \frac{[\mu_{22}(t) - \mu_{33}(t)]}{[\mu_{22}(t) + \mu_{33}(t)]} \qquad (2.33)$$

$$\rho_{13} = \frac{[\mu_{11}(t) - \mu_{33}(t)]}{[\mu_{11}(t) + \mu_{33}(t)]}$$

Note that when two principal variances approach each other in value, the corresponding principal cross correlation coefficient approaches zero and the other two cross correlation coefficients approach the same value. In the limit when these principal variances become equal, the corresponding principal axes become undefined. This behavior corresponds to the three-dimensional stress problem when a deviator stress along one axis is superposed upon a hydrostatic state of stress resulting in only one identifiable principal axis which lies along the axis of the deviator stress. Obviously, it becomes difficult to reliably predict the directions of the principal axes when principal variances approach each other in value.

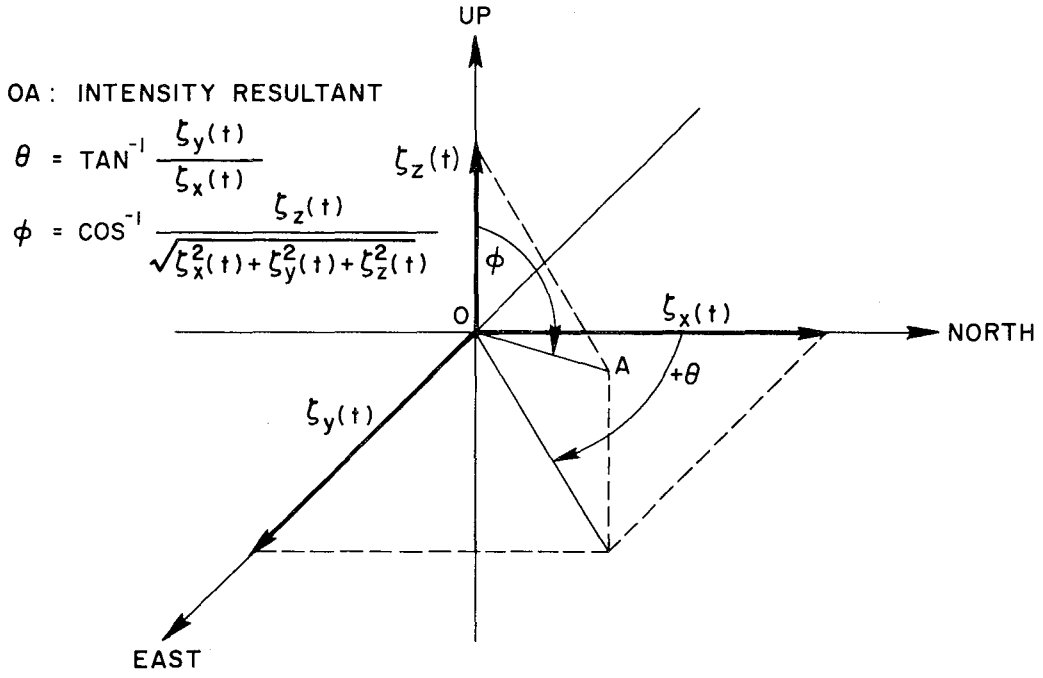


Fig. 2.1 Direction angles of intensity function in three-dimensional space.

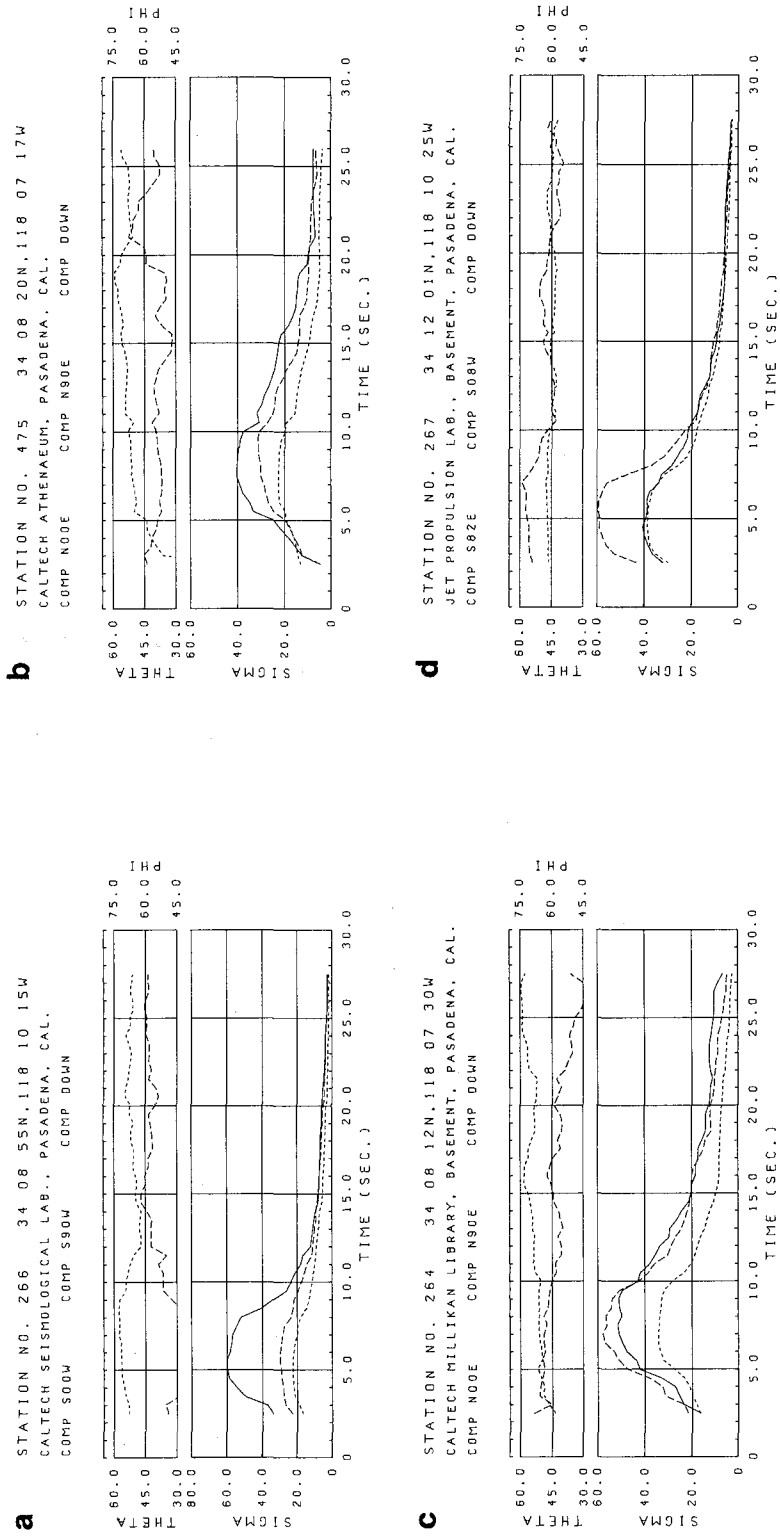


Fig. 2.2 Time dependency of intensity functions along instrument axes.

NOT REPRODUCIBLE

III. CHARACTERISTICS OF GROUND MOTION FROM MOVING-WINDOW ANALYSIS

A. TIME DOMAIN ANALYSIS

1. General

In a previous paper [32], variances and covariances of recorded ground motions were evaluated for successive time intervals using the relation

$$\mu_{ij} = < [a_i(t) - \bar{a}_i][a_j(t) - \bar{a}_j] >_{t_1}^{t_2} \qquad i,j = x,y,z \tag{3.1}$$

in which the time averages are taken over the interval $t_1 \leq t < t_2$ but where the mean values $\bar{a}_i$ and $\bar{a}_j$ are found by averaging $a_i(t)$, $a_j(t)$ over the entire duration of motion. Locations of principal axes and magnitudes of corresponding principal variances were obtained for earthquake motions recorded at three stations in California and three stations in Japan. The results show that the directions of principal axes were not fixed for successive time intervals.

In the present investigation, recognizing that intensity functions for three components change in a different manner with each other, variances and covariances are obtained as continuous functions of time t_o using the so-called "moving-window" technique, i.e. using the relation

$$\mu_{ij}(t_o,\Delta T) = < [a_i(t) - \bar{a}_i][a_j(t) - \bar{a}_j] >_{t_o - \frac{\Delta T}{2}}^{t_o + \frac{\Delta T}{2}} \qquad i,j = x,y,z \tag{3.2}$$

where the time averages are taken over the interval ΔT centered at time t_o [9]. Having obtained all nine covariance functions for the

recorded components of motion in accordance with Eqs. (3.2), the corresponding time dependent directions of principal axes can be obtained, i.e. giving the principal transformation matrix as a function of time t_o and time window length ΔT_o, i.e. $\underline{P} = \underline{P}\ (t_o, \Delta T)$. This time dependent principal transformation matrix then allows one to obtain the time dependent directions of principal axes of components of motion $a_x(t)$, $a_y(t)$ and $a_z(t)$ and their corresponding principal variances $\sigma_1^2(t_o)$, $\sigma_2^2(t_o)$ and $\sigma_3^2(t_o)$.

One finds increased fluctuations in $\mu_{ij}(t_o, \Delta T)$ and the corresponding directions of principal axes as the value of time window length ΔT in Eqs. (3.2) is taken shorter and shorter. In fact, as $\Delta T \to 0$, the major principal axis of ground motion coincides with the instantaneous resultant acceleration vector which changes its direction rapidly in a random fashion over the entire sphere of space. Therefore, ΔT should be taken sufficiently long so that the higher frequency fluctuations are essentially removed but the slower time dependent characteristics are retained, i.e. the time average over duration ΔT will be essentially equal to the average taken across the ensemble.

The direction of each principal axis is given by angles ϕ and θ as shown in Fig. 3.1. Angle ϕ is the declination of the principal axis from the vertical axis through point "0"; thus, its value falls in the range $0° \leq \phi \leq 90°$. Angle θ is measured from the North axis to the projection of the northerly extension of the principal axis on a horizontal plane containing point "0". By this definition, θ lies in the range $-90° < \theta \leq + 90°$. The angle θ_E in Fig. 3.1 represents the horizontal direction of an axis passing through the accelerograph site location (point "0") and the reported epicenter. Since this angle is measured in a similar manner to that of angle θ,

it also lies in the range $-90° < \theta_E \leq + 90°$. Length OA in Fig. 3.1 represents the magnitude of the variance of principal ground motion. The square root of this quantity (sigma) can be used to represent the intensity functions of the corresponding nonstationary processes [22].

2. Results At Station No. 264 Basement Of The Millikan Library, CALTECH

Direction angles ϕ and θ and the square root of the principal variance (σ) have been obtained as functions of time t_o for the major, minor and intermediate principal axes of the ground motion at station No. 264, the basement of the Millikan Library at the California Institute of Technology, Pasadena, California.

The results are shown in Figs. 3.2a through 3.2c. These results of Figs. 3.2a, 3.2b and 3.2c are respectively obtained by using time window length ΔT equal to two, five and ten seconds at discrete values of one-half second apart. The solid, short-dashed and intermediate-dashed curves in these figures represent respectively the major, minor and intermediate principal axes and the horizontal long-dashed straight line represents the direction θ_E to the reported epicenter. It should be noted from the definition of θ that as the horizontal direction of a principal axis rotates in a continuous manner through the east-west direction, the value of θ changes instantaneously by 180°, i.e. changes from +90° to -90° or from -90° to +90° depending upon whether the horizontal projection of the principal axis is rotating clockwise or counterclockwise. This explains the sudden jumps which appear in the functions of θ which take place over single spacings of the prescribed discrete values of t_o, namely over one-half second spacings.

In the present report, ΔT is taken as two seconds for several short durations of motion, say less than twenty seconds, and taken as

five seconds for all other records. Angles ϕ and θ and σ are evaluated for discrete values of t_o spaced one-half second apart and are interpolated by straight lines.

It should be noticed that if ground motion processes are represented by the product of stationary random processes and deterministic intensity functions and if the intensity functions for three components vary with time in the same manner, i.e. satisfy Eqs. (2.1), any two of the principal variance functions differ from each other by a fixed constant only in which case the directions of principal axes are fixed, i.e. they are time invariant over the entire duration.

3. Results Through The Time Domain

The time domain moving-window analysis described above has been applied to the ground motions recorded at numerous stations during the San Fernando earthquake of February 9, 1971. Acceleration records at 99 stations have been evaluated. Nearly half of them are located in the high- or intermediate-rise buildings in the cities of Los Angeles, Hollywood and Beverly Hills, which are sited about 40 km south of the epicenter.

Some of these accelerograph locations are in basements and at the ground level of higher buildings, some are in smaller buildings and some are on free field. The motions can be considered representative of the ground motions. The accelerograph at each station has its own characteristics [48] and was triggered independently of other located nearby. At station No. 290, two accelerographs were installed, one of which was a temporary accelerograph.

The accelerograph locations were divided into six area groups, A through F. Certain data associated with these stations, such as

station identification number, station location, peak accelerations, building structural type and local site geology are given in Tables 3.1 through 3.5 and Table A.1,respectively.

Area A (CALTECH)

Area A is located on the campus of California Institute of Technology which contains four stations, namely No. 267, the Jet Propulsion Laboratory, No. 266, the Seismological Laboratory, No. 264, the Millikan Library and No. 475, the Athenaeum. Numerous investigations on the dynamic behavior and the soil-structure interaction effects of these buildings have been carried out [27, 12, 21, 15]. The accelerographs at these four stations are reported to have been triggered at the same time, i.e. to have common time bases [24]. The results for these stations are shown in Figs. 3.3a through 3.3d.

Area B (Wilshire)[12, 17]

Area B having seven stations in the basements of high-rise buildings is located along Wilshire Boulevard in downtown Los Angeles. Each instrument in this area was triggered independently upon the arrival of seismic waves. However, one can estimate a common time base by reading the arrival time of certain high frequencies in the acceleration and velocity traces. This procedure is reported to provide an accurate estimate [17]. The local geology in this area consists of alluvium and plestocene rock and is classified as an intermediate type or a soft type. The results for these seven site locations are shown in Figs. 3.4a to 3.4g.

Area C (Lake Hughes)

Area C located in the vicinity of Lake Hughes consists of four stations array Nos. 1, 4, 9 and 12. The site geology in this area

is designated as a hard soil type. Due to the wide separations between stations in this area, it is impossible to establish a common time base for the recorded accelerograms. The results for these stations are shown in Figs. 3.5a through 3.5d.

Area D (Beverly)

Area D contains four stations; two in basements and two at the first floor level of high-rise buildings. These four stations, Nos. 137, 148, 172 and 145, are located on intermediate geology at the corner of Beverly Boulevard and Figueroa Street in downtown Los Angeles and are very close to each other. The distance from the epicenter to the stations is about 40 km and the direction to the epicenter is about N 20° W. Figures 3.6a-3.6d show the time dependent characteristics of principal axes of motion at these stations.

Area E (Santa Monica) [17]

This area contains four stations located in high-rise buildings having from 15 to 30 stories. These buildings are located on soft geology about 40 km from the epicenter along Santa Monica Boulevard near Beverly Hills in the west part of Los Angeles. The results for these stations are presented in Figs. 3.7a through 3.7d. Although the wave propagation paths are different, one may be able to investigate the relative influence of intermediate to soft geological conditions on ground motion characteristics by comparing the results for stations in areas D and E.

Area F (Figueroa)

Area F is located about 40 km S 18° E of the epicenter. The stations in this area are located in intermediate-and high-rise buildings along Figueroa Street, south of area D (Beverly) in downtown

Los Angeles. It has been reported that the accelerograph at station No. 154 was installed on the 2nd floor; however, because the floor of the building is numbered from the adjoining building, this floor actually corresponds to ground level [29]. The time dependent characteristics of principal axes of motions for these six stations are included in Appendix A.

The results obtained for 70 other stations, not included in area groups A-F, are presented in Appendix B.

4. Observation of Results

Although, the functions of principal transformation shown in Figs. 3.3 through 3.7 and in Appendices A and B have numerous unexplainable features, certain correlations should be noted as follows:

(1) Usually during the early periods of low intensity motion, either the major or the intermediate principal axis is nearly vertical, i.e. the vertical component represents a large amount of energy in comparison with the horizontal components.

(2) Later except for several motions recorded in high-rise buildings and at stations close to the epicenter, the major and intermediate principal axes shift towards horizontal positions with the minor principal axis taking the nearly vertical position; thus, the angle between the horizontal directions of the major and intermediate principal axes is about 90°.

(3) Following the shift of the major principal axis towards a horizontal position, the horizontal directions of the major and intermediate principal axes are sometimes suddenly interchanged. This interchange which occurs after the period of

high intensity motion is due to a corresponding change in the direction along which the seismic waves have maximum energy.

(4) After the major and intermediate principal axes have moved to their nearly horizontal positions, the minor and intermediate principal axes (and in some cases, the minor and major principal axes) retain approximately the same horizontal direction angles θ over large time intervals. This property suggests geometrically that the plane containing the minor and intermediate principal axes also contains the vertical axis. When the minor principal axis takes a nearly vertical position, slight changes in its direction cause large fluctuations in the angle θ. Due to this high sensitivity, the fluctuations in θ have little significance in this case.

(5) For many motions measured in high-rise buildings, some of the more common correlative features related to principal axes seem to be eliminated due to possible soil-structure interaction effects. These interaction effects are most apparent during the strong motion following that time at which the minor axis shifts to its nearly vertical position.

(6) Usually during the period of high intensity motion, the horizontal direction of either the major or the intermediate principal axis is towards the faults slip zone. This characteristic suggests that the direction along which seismic waves contain maximum energy either coincides with the direction to the fault slip zone or is at right angles to it.

(7) The shape of the intensity functions for the minor principal axis looks fairly flat for those stations located on soft to intermediate types of geology.

For area groups A-F, specific correlations and dissimilar features can be noted as follows:

(1) In Figs. 3.3, the possible interchange of major and intermediate principal axes at stations Nos. 264 and 475 occurs at a time around 10 second. The directions of principal axes and corresponding intensities are, however, quite dissimilar with each other, even though the distance between stations is not more than 400 m. During the early period of motion, the direction angle θ of the major principal axis is approximately 90° for both stations Nos. 267 and 266. Later in the motion, the direction angle shifts to nearly 45° in each case.

(2) In Figs. 3.4, the general features of principal directions at various stations agree reasonable well with one another, especially at stations Nos. 211, 208, 196 and 199 where the major principal axis is closely directed towards the reported epicenter during periods of high intensity motion. Also the intensity functions for stations Nos. 211 and 208 are quite similar to each other; however for stations Nos. 196 and 199, they are dissimilar.

(3) In Figs. 3.5, little correlation, if any, can be seen for the four stations represented. This is to be expected, however, since these stations are spaced at distances which are large compared to the significant seismic wave lengths in the accelerograms and their geological conditions and wave propagation paths could be quite different with each other.

(4) Among the four stations of area group D represented in Figs. 3.6, the intensity functions look quite similar except for

station No. 148. The directions of principal axes are quite similar for stations Nos. 145 and 172 and are also similar for stations Nos. 137 and 148. They are, however, different between those two groups.

(5) In Figs. 3.7, the directions of the major principal axes for stations Nos. 440, 184 and 187 are quite similar with one principal axis directed towards the reported epicenter in each case. These same features at station No. 425 are, however, dissimilar.

Figures 3.8 through 3.11 are maps of areas in southern California showing the horizontal directions of the major and intermediate principal axes at the period when the motions are of highest intensity. The map in Fig. 3.9 is an enlargement of the small rectangular area in Fig. 3.8 showing the extended Los Angeles and San Fernando regions. Similarly the map in Fig. 3.10 is an enlargement of the small rectangular area in Fig. 3.9 showing the cities of Los Angeles, Hollywood and Beverly Hills. The maps in Figs, 3.11a through 3.11c show area groups B, E and F, respectively.

While the correlation is not strong, there is a tendency of the directions of the major principal axis or, in some cases, the intermediate principal axis to point in the general direction of the fault slip zone as shown in Fig. 3.9 [20] which is also the general direction towards the previously reported locations of surface fault traces south of the epicenter [13]. The concept of intensity defined here is identical to that defined by Arias [2]. Therefore, one can speculate that the direction of the major principal axis coincides with the direction to maximum energy release in the fault slip zone.

Obviously, in the case of motions produced by the San Fernando earthquake, such factors as the complex mechanism of strain energy release, the dispersion of seismic waves due to variable geological conditions, the complex geology around the fault slip zone, the closeness of the recording stations to the fault slip zone and the possible influence of soil-structure interaction weaken this correlation. It should be pointed out that the horizontal directions of the major and intermediate principal axes obtained from time averaging over the entire durations of motion are in most cases quite similar to those shown in Figs. 3.8 through 3.11.

B. FREQUENCY DOMAIN ANALYSIS

1. General

The moving-window technique, as applied in the time domain formulation, can be applied in the frequency domain as well. In this case, however, the variances and covariances are evaluated as continuous functions of frequency f_o. Using the Fourier integral transformation, variances and covariances are obtained through the relation

$$\mu_{ij}(f_o,\Delta f) = \left\langle \left[\int_{-f_o-\frac{\Delta f}{2}}^{-f_o+\frac{\Delta f}{2}} A_i(2\pi if)e^{2\pi ift}\,df + \int_{f_o-\frac{\Delta f}{2}}^{f_o+\frac{\Delta f}{2}} A_i(2\pi if)e^{2\pi ift}\,df \right] \cdot \left[\int_{-f_o-\frac{\Delta f}{2}}^{-f_o+\frac{\Delta f}{2}} A_j(2\pi if)e^{2\pi ift}\,df + \int_{f_o-\frac{\Delta f}{2}}^{f_o+\frac{\Delta f}{2}} A_j(2\pi if)e^{2\pi ift}\,df \right] \right\rangle_0^T \qquad (3.3)$$

$$i,j = x,y,z$$

where

$$A_i(2\pi if) = \int_0^T a_i(t)e^{-2\pi ift}\,dt$$

$$A_j(2\pi if) = \int_0^T a_j(t)e^{-2\pi ift}\,dt \qquad (3.4)$$

and where T denotes the total duration of ground motion.

In the frequency domain formulation, the principal transformation matrix $\underline{P}$ is given as a function of frequency f_o and frequency bandwidth Δf, i.e. $\underline{P} = \underline{P}\ (f_o, \Delta f)$. This formulation allows one to investigate directions of principal axes, variances, covariances, etc. associated with only those frequencies of ground motion in the range of $(f_o - \frac{\Delta f}{2}) \leq f < (f_o + \frac{\Delta f}{2})$. Hopefully, this approach can be used to reveal certain characteristic features of the various types of seismic waves associated with strong ground motions.

2. Results at Station No. 264

Direction angles ϕ and θ and the square root of the principal variance (σ) have been obtained as functions of frequence f_o for the major, minor and intermediate principal axes of the ground motion at station No. 264, located in the basement of the Millikan Library at the California Institute of Technology, Pasadena, California.

Using the frequency domain formulation, one can obtain frequency dependent characteristics of principal axes as shown in Figs. 3.12a through 3.12c. Again the solid, short-dashed and intermediate-dashed curves represent the results for the major, minor and intermediate principal axes, respectively. These figures show properties of principal axes using different values for frequency bandwidth (Δf) and for spacings between discrete values of frequencies (f_o). The values of bandwidth and spacings represented in Figs. 3.12a, 3.12b and 3.12c are, respectively, 0.488 and 0.244, 0.977 and 0.488, and 1.953 and 0.488 Hz. Based on these results, it was judged that values near 0.977 and 0.488 Hz could be used for the motions recorded at other stations.

3. Results Through The Frequency Domain

The moving-window formulation in the frequency domain has been carried out at 29 site stations in the area groups previously described. The results for those stations in area groups A through F are shown in Figs. 3.13 and 3.14 and in Appendices A and C. Information on site locations can be found in Tables 3.1 through 3.5 and in Table A.1.

4. Observation of Results

While many features of the frequency domain functions shown in Figs. 3.13 and 3.14 and in Appendices A and C are as unexplainable as certain features of the time domain functions, there are some characteristics and correlations which can be identified among area groups or geological conditions as follows:

(1) Usually in the lower frequency range, the major and intermediate principal axes take nearly horizontal positions, while in the higher frequency range, the minor principal axis shifts towards a horizontal position with the major principal axis taking a vertical position.

(2) The major and intermediate principal axes are observed to interchange their horizontal positions several times at most stations. At station No. 211 (Fig. 3.14b), they interchange positions at frequencies around 1.0 and 3.0 Hz. At station No. 137 (Fig. C.2a), they interchange positions three times at frequencies around 1.5, 4.5 and 7.0 Hz.

(3) Among several stations, such as Nos. 202, 196, 199, 126, 127, 172, 184 and 187 (Figs. 3.14, C.1, C.2 and C.3), the horizontal direction of either the major or the intermediate principal

axis coincides with the general direction to the reported epicenter. The relationship between general direction of the major principal axis and direction to the epicenter is, however, not highly correlated.

(4) Usually, the principal variances along the minor principal axis are more uniform than the principal variances along the major or intermediate principal axis. Therefore, it may be concluded that the spectral density distribution for the minor principal axis is approximately uniform, i.e. the spectral density distribution is similar to white noise.

(5) Based on the results in Figs. 3.13, the motions for sites on hard geology generally have peak variances in the higher frequency range and are quite narrow band. However, motions for sites on soft geology generally have peak variances in the lower frequency range and are quite wide band. This observation is in general agreement with site dependency effects as previously reported in the literature [40]. To check further for evidence of site effects on the dominant frequency, i.e. the frequency corresponding to maximum intensity, the results shown in Fig. 3.15 were plotted. This figure shows number of stations versus dominant frequency for three site conditions (hard, intermediate and soft) within area groups A through F. The correlation in this case is quite weak; however, it should be recognized that the site classifications are not too reliable.

C. MAXIMUM VARIANCES AND COVARIANCES

1. General

Cross correlation coefficients, obtained through the relation

$$\rho_{ij} = \frac{< [a_i(t) - \bar{a}_i][a_j(t) - \bar{a}_j] >}{\sigma_i \sigma_j} \qquad (3.5)$$

$$i,j = x,y,z$$

take values in the range of -1 and +1. If the ground motion processes are completely dependent, i.e. they are identically the same, the cross correlation coefficients are either +1 or -1 depending upon the directions of the processes. On the other hand, if the processes are completely independent of each other, the cross correlation coefficients equal zero. As previously shown ground motions along principal axes are independent in a statistical sense; therefore, the corresponding cross correlation coefficients equal zero. Axes along which the ground motions provide maximum cross correlation coefficients can be identified by the procedure previously described. In the following section of this report, principal variances and principal cross correlation coefficients obtained by the moving-window technique are presented.

2. Results of Maximum Variances and Covariances

Principal variances, maximum covariances and principal cross correlation coefficients are evaluated for motions recorded at stations in area groups A through F. The results for stations in area groups A and B are shown in Figs. 3.16 and 3.17, respectively, and those for other stations are included in Appendicies A and D. Each figure consists of four diagrams showing the following.

(1) Principal variances along the major, minor and intermediate principal axes which are represented by the solid, short-dashed and intermediate-dashed curves, respectively.

(2) Ratios of the intermediate and minor principal variances to the major principal variance which are represented by the intermediate-dashed and short-dashed curves, respectively.

(3) Mean variances equal to $\frac{1}{2}\ [\mu_{22}(t) + \mu_{33}(t)]$, $\frac{1}{2}\ [\mu_{11}(t) + \mu_{33}(t)]$ and $\frac{1}{2}\ [\mu_{11}(t) + \mu_{22}(t)]$ along axes giving the corresponding maximum covariances $\frac{1}{2}\ [\mu_{22}(t) - \mu_{33}(t)]$, and $\frac{1}{2}\ [\mu_{11}(t) - \mu_{33}(t)]$ which are shown by the solid, intermediate-dashed and short-dashed curves, respectively.

(4) Principal cross correlation coefficients ρ_{23}, ρ_{13} and ρ_{12} obtained as ratios of the maximum covariance to the corresponding mean variance, e.g. $\rho_{23}(t) = [\mu_{22}(t) - \mu_{33}(t)]/[\mu_{22}(t) + \mu_{33}(t)]$, which are represented by the solid, intermediate-dashed and short-dashed curves, respectively.

3. Observation of Results

Based on the time dependent properties of principal variances, the variances along principal axes vary with time in different manners. Observed, however, that the ratios of the intermediate and minor principal variances to the major principal variance are stable during periods of high intensity motion. Since high energy is represented during these periods, their statistical properties will be considered of major importance in characterizing the ground motion process. Therefore, the most significant statistical properties were evaluated at that time when the motion was of maximum intensity. Such results obtained for

each geological classification are summarized in Table 3.6. It is apparent that the ratios of the intermediate and minor principal variances to the major principal variance, though they differ with geological conditions, are approximately 0.5-0.7 and 0.15-0.25 with the standard deviations of 0.2 and 0.1, respectively.

Cross correlation coefficients for motions along instrument for many earthquakes including the San Fernando earthquake were reported in the literature [11]. Statistical properties of these cross correlation coefficients are shown in Table 3.7. Of the 104 instrument stations included in this table, several are located at the top of buildings.

Similar to those of principal variances, statistical properties of cross correlation coefficients evaluated during periods of high intensity motion are shown in Table 3.8. Using these results, average ratios of principal variances μ_{33}/μ_{22}, μ_{33}/μ_{11} and μ_{22}/μ_{11} were found to be 0.50, 0.22 and 0.43 on hard geology, 0.21, 0.15 and 0.73 on intermediate geology and 0.31, 0.17 and 0.56 on soft geology, respectively. These ratios correspond with the ratios of principal variances at the time of highest intensity as shown in Table 3.6. Although the number of samples is quite limited, it can be concluded that there is a general correlation between geological classification and ratios of principal variances. Based on the results in Table 3.8, the principal cross correlation coefficient between the major and intermediate principal axes (ρ_{12}) is smaller for soft geology than for hard geology. In all cases studied, the minor principal axis at time of maximum intensity is nearly vertical. When this occurs and the principal cross correlation coefficient ρ_{12} equals zero, the motions

in the horizontal plane are statistically independent regardless of the directions of components.

TABLE 3.1 ACCELEROGRAPH SITE INFORMATIONS - AREA A [29]

STATION ID NUMBER*	STATION LOCATION	POSITIVE DIRECTIONS OF ACCELEROGRAPH	PEAK ACC. (GAL)	APPROX. DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER** (DEGREE)	BUILDING STRUCTURAL TYPE	ABBREVIATED SITE GEOLOGY ( )***
267	Pasadena Jet Propulsion Laboratory Basement	S82E S08W DOWN	207.8 139.0 -126.3	30.1	-42	9-story St. building	Sandy Gravel (I)
266	Pasadena Seismological Laboratory	S00W S90W DOWN	- 87.5 -188.6 83.5	34.7	-36	2-story building	Weathered Granitics (H)
264	Pasadena Millikan Library Basement	N00E N90E DOWN	-198.0 -181.6 - 91.2	38.4	-40	9-story RC building	Approx. 1000' of Alluvium upon Granite (S)
475	Pasadena Athenaeum	N00E N90E DOWN	93.5 -107.3 - 92.9	38.4	-41	2 1/2-story RC building	Approx. 1000' of Alluvium upon Granite (S)

* Permanent identification number in annual list of stations issued by the Seismological Field Servey, NOS-NOAA

** Direction angles are measured from the north in clockwise.

*** Site classification. (S), (I) and (H) correspond to soft, intermediate and hard site classifications, respectively [51].

TABLE 3.2 ACCELEROGRAPH SITE INFORMATIONS - AREA B [29]

STATION ID NUMBER*	STATION LOCATION	POSITIVE DIRECTION OF ACCELEROGRAPH	PEAK ACC. (GAL)	APPROX. DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER** (DEGREE)	BUILDING STRUCTURAL TYPE	ABBREVIATED SITE GEOLOGY ( )***
217	3710 Wilshire Blvd. Basement	S00W S90W DOWN	-146.7 -155.7 - 73.1	38.5	-12	11-story RC Building	Alluvium (I)
211	3550 Wilshire Blvd. Basement	NORTH WEST UP	153.6 -129.7 54.3	38.6	-13	21-story St. Building	Alluvium Water table at 35' (S)
208	3470 Wilshire Blvd. Subbasement	N00E S90W DOWN	-133.8 111.8 - 47.3	38.7	-13	11-story RC Building	Alluvium (S)
431	616 South Normandie Ave. Basement	N00E S90W DOWN	-107.6 112.0 - 51.6	38.6	-13	17-story RC Building	Alluvium Siltstone at 25' (I)
202	3411 Wilshire Blvd. 5th Basement	SOUTH WEST UP	-104.2 125.2 53.8	38.5	-13	31-story St. Building	Siltstone Water table at Basement level (I)
196	3345 Wilshire Blvd. Basement	S00W N90E DOWN	-108.3 - 88.2 60.2	38.6	-14	12-story RC Building	Alluvium (S)
199	3407 6th Street Basement	S00W N90E DOWN	-158.2 -161.9 - 55.5	38.6	-14	7-story 2 St. and 5 RC Building	Alluvium (S)

TABLE 3.3 ACCELEROGRAPH SITE INFORMATIONS - AREA C [29]

STATION ID NUMBER*	STATION LOCATION	POSITIVE DIRECTION OF ACCELEROGRAPH	PEAK ACC. (GAL)	APPROX. DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER** (DEGREE)	BUILDING STRUCTURAL TYPE	ABBREVIATED SITE GEOLOGY ( )***
125	Lake Hughes Array No. 1	N21E S69E DOWN	-145.5 108.9 - 93.0	30.9	- 8	Small Building	Granitic (H)
126	Lake Hughes Array No. 4	S69E S21W DOWN	168.2 -143.5 150.8	28.0	-16	Small Building	Weathered Granitic (H)
127	Lake Hughes Array No. 9	N21E N69W DOWN	119.3 -109.4 71.5	27.7	-33	Small Building	Gneiss (H)
128	Lake Hughes Array No. 12	N21E N69W DOWN	-346.2 277.9 -105.3	24.4	-38	Small Building	Eocene Sandstone below a shallow (10'±) layer of Alluvium (I)

TABLE 3.4 ACCELEROGRAPH SITE INFORMATIONS - AREA D [29]

STATION ID NUMBER*	STATION LOCATION	POSITIVE DIRECTION OF ACCELEROGRAPH	PEAK ACC. (GAL)	APPROX. DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER** (DEGREE)	BUILDING STRUCTURAL TYPE	ABBREVIATED SITE GEOLOGY ( )***
137	Water and Power Building Basement	N50W S40W DOWN	126.5 -169.2 - 67.2	41.1	-19	15-story St. Building	Miocene Siltstone (I)
148	234 Figueroa St. Basement	S37E S53E UP	195.6 -188.3 - 67.5	40.4	-18	17-story RC Building	25' of Alluvium over Shale Water at 20' (I)
172	800 West First St. 1st Floor	N37E N53W UP	86.8 138.0 60.9	40.4	-19	31-story St. Building	Pliocene Siltstone (I)
145	222 Figueroa St 1st Floor	N53W S37W UP	149.4 -126.8 43.2	40.4	-19	17-story RC Building	25' of Alluvium over Shale Water at 20' (I)

TABLE 3.5 ACCELEROGRAPH SITE INFORMATIONS - AREA E [29]

STATION ID NUMBER*	STATION LOCATION	POSITIVE DIRECTION OF ACCELEROGRAPH	PEAK ACC. (GAL)	APPROX. DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER** (DEGREE)	BUILDING STRUCTURAL TYPE	ABBREVIATED SITE GEOLOGY ( )***
425	1800 Century Park East Basement	N54E S36E DOWN	- 97.9 - 82.3 - 62.5	37.5	3	15-story RC Building	Silt and Sand Layers. Water table at 70-80' (S)
440	1880 Century Park East 1st Level	N54E N36W DOWN	-114.4 126.5 - 62.5	37.6	3	16-story St. Building	Silt and Sand Layers. Water table at 70-80' (S)
184	1900 Avenue of Stars Basement	N44E S46E UP	- 79.9 - 84.2 - 57.4	37.9	3	27-story St. Building	Silt and Sand Layers. Water level at 70' (S)
187	1901 Avenue of Stars Subbasement	N46W S44W DOWN	133.8 147.1 - 66.7	38.5	3	19-story St. Building	Silt and Sand Layer Water table at 70-80' (S)

TABLE 3.6 STATISTICAL PROPERTIES OF PRINCIPAL VARIANCES AT THE PERIOD OF HIGHEST INTENSITY

GEOLOGICAL CLASSIFICATION			HARD	INTERMEDIATE	SOFT	
NUMBER OF SAMPLES			3	8	14	25
Ratios of principal variances to the intensity tensor	Mean	Major	0.61	0.53	0.58	0.57
		Inter.	0.26	0.39	0.33	0.34
		Minor	0.13	0.08	0.10	0.10
	Standard deviation	Major	0.12	0.05	0.06	0.07
		Inter.	0.07	0.05	0.07	0.07
		Minor	0.05	0.04	0.04	0.04
	Coefficient of Variation	Major	0.19	0.08	0.10	0.12
		Inter.	0.27	0.12	0.21	0.22
		Minor	0.39	0.44	0.36	0.40
Ratios of the intermediate and minor principal variances to the major principal variance	Mean	Inter.	0.44	0.74	0.58	0.61
		Minor	0.23	0.16	0.17	0.17
	Standard deviation	Inter.	0.18	0.13	0.16	0.18
		Minor	0.12	0.07	0.06	0.07
	Coefficient of Variation	Inter.	0.41	0.18	0.28	0.29
		Minor	0.52	0.46	0.38	0.43

TABLE 3.7 STATISTICAL PROPERTIES OF CORRELATION COEFFICIENTS FOR STRONG MOTION ACCELEROGRAMS RECORDED AT 104 SITES [11]

COMPONENTS	TRUE MEAN	STANDARD DEVIATION	ABSOLUTE MEAN	ABSOLUTE MAXIMUM	ABSOLUTE MINIMUM
H_1, H_2	0.0029	0.2116	0.1632	0.6801	0.0014
H_1, V	0.0187	0.1774	0.1387	0.4957	0.0004
H_2, V	0.0055	0.1841	0.1321	0.7430	0.0005

TABLE 3.8 STATISTICAL PROPERTIES OF PRINCIPAL CROSS CORRELATION COEFFICIENTS AT THE PERIOD OF HIGHEST INTENSITY

GEOLOGICAL CLASSIFICATION			HARD	INTERMEDIATE	SOFT	
NUMBER OF SAMPLES			3	8	14	25
Principal cross correlation coefficients	Mean	ρ_{23}	0.33	0.65	0.53	0.54
		ρ_{13}	0.63	0.73	0.72	0.71
		ρ_{12}	0.40	0.16	0.28	0.26
	Standard deviation	ρ_{23}	0.07	0.15	0.19	0.19
		ρ_{13}	0.16	0.11	0.09	0.11
		ρ_{12}	0.19	0.09	0.14	0.15
	Coefficient of Variation	ρ_{23}	0.20	0.23	0.36	0.35
		ρ_{13}	0.26	0.15	0.13	0.15
		ρ_{12}	0.47	0.58	0.50	0.58

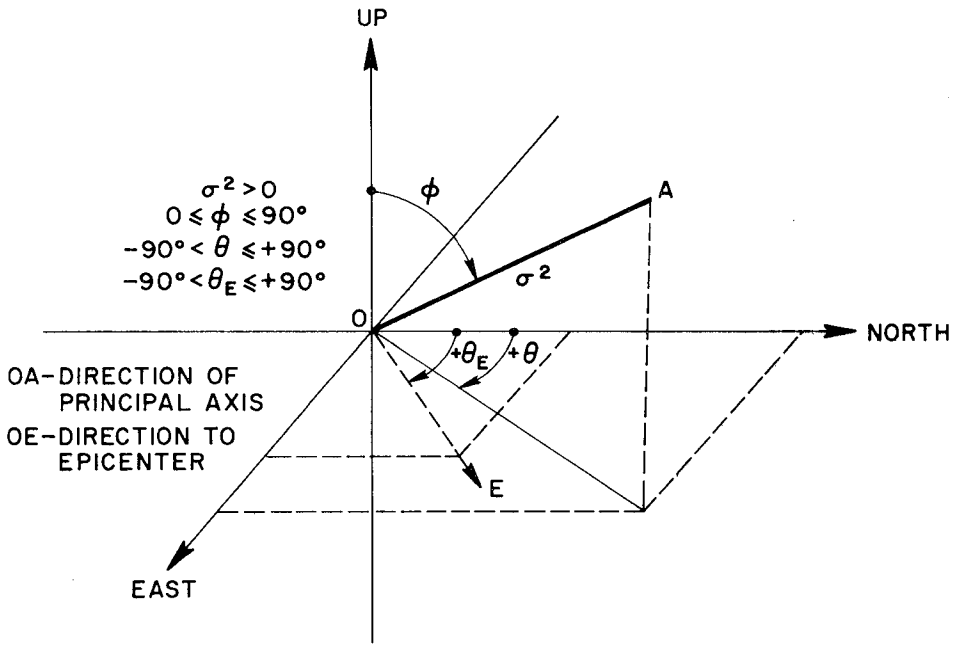


Fig. 3.1 Directions of principal axes in three-dimensional space.

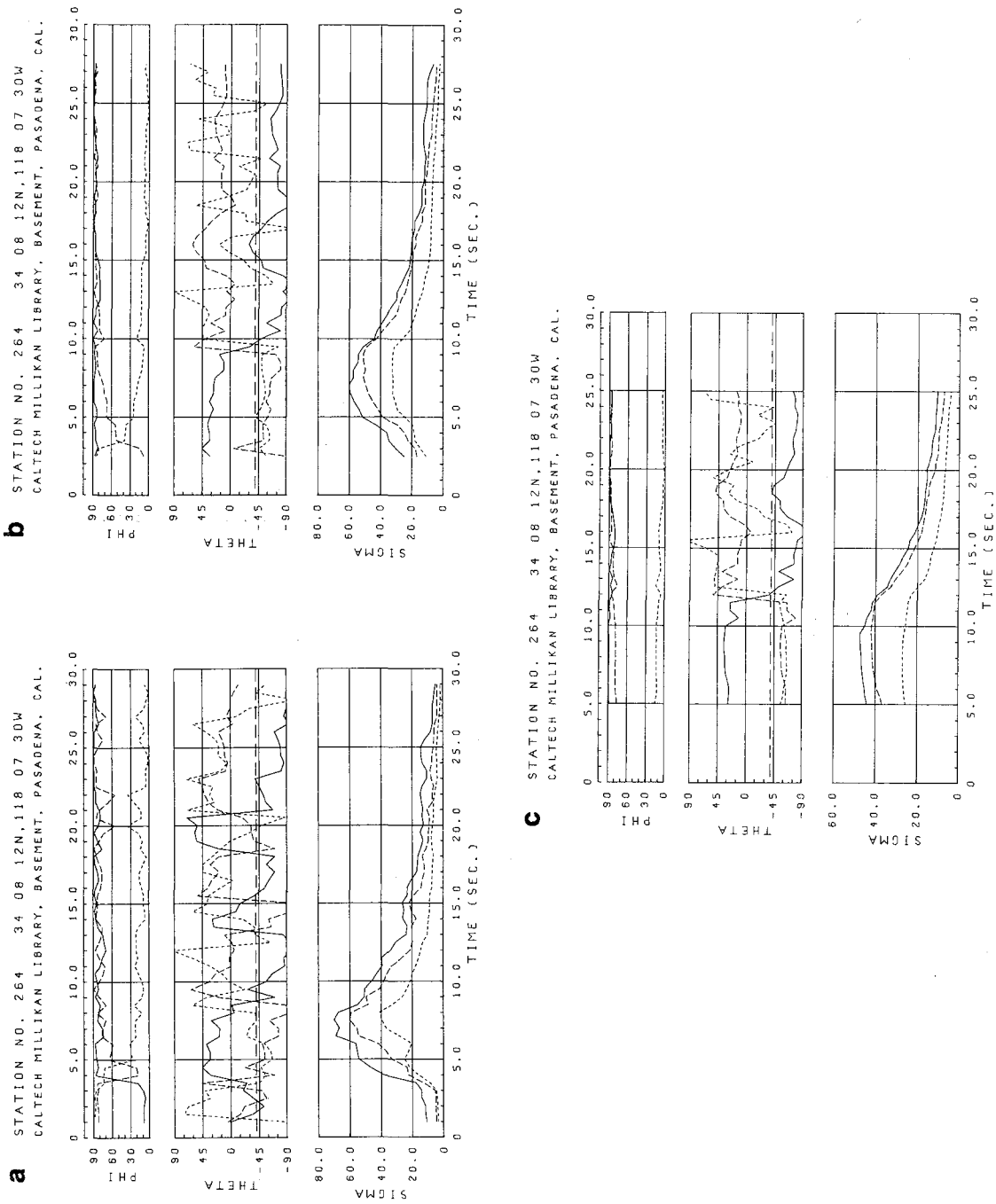


Fig. 3.2 Time dependent directions of principal axes and square root of principal variances at station No. 264.

NOT REPRODUCIBLE

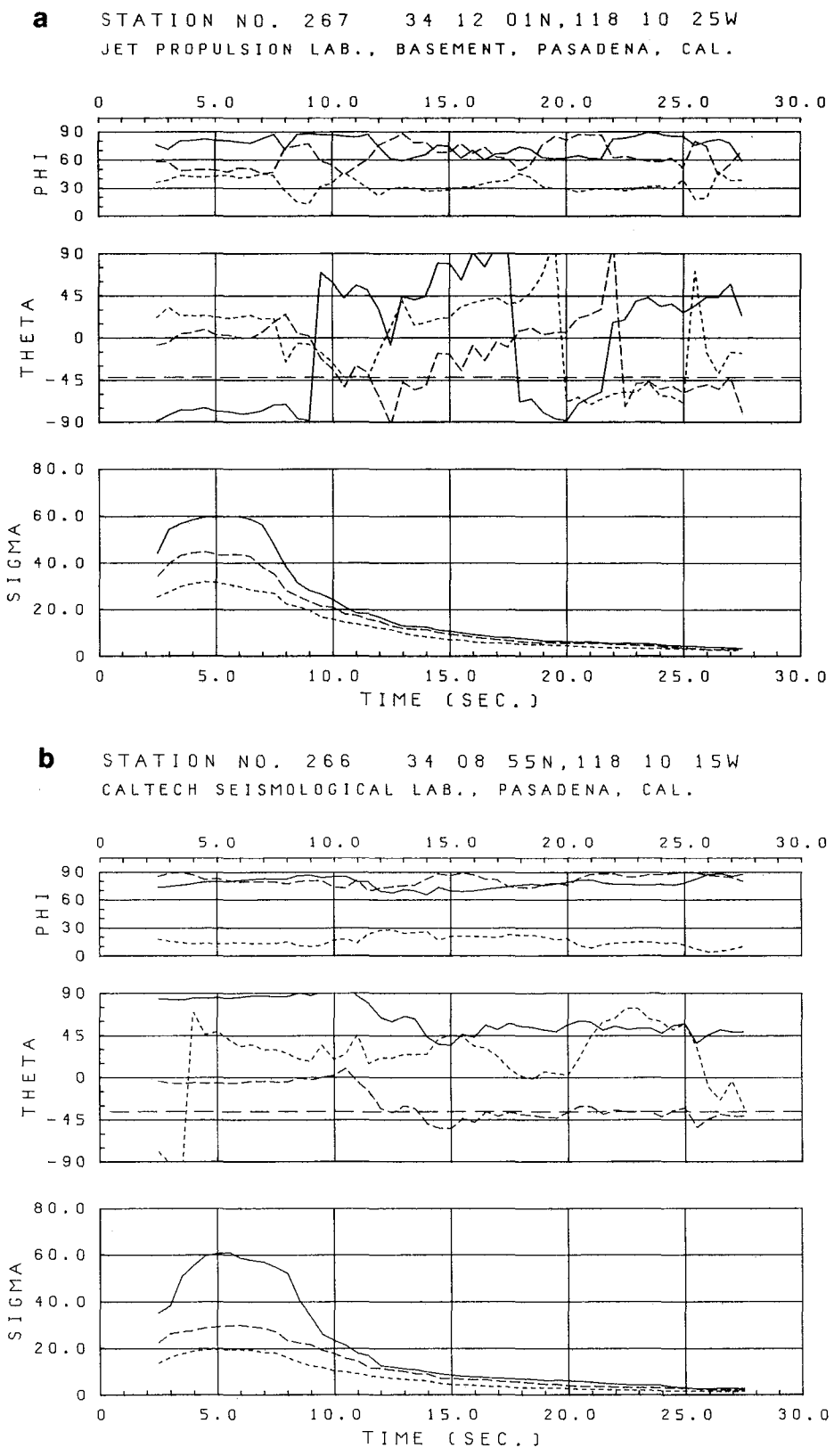
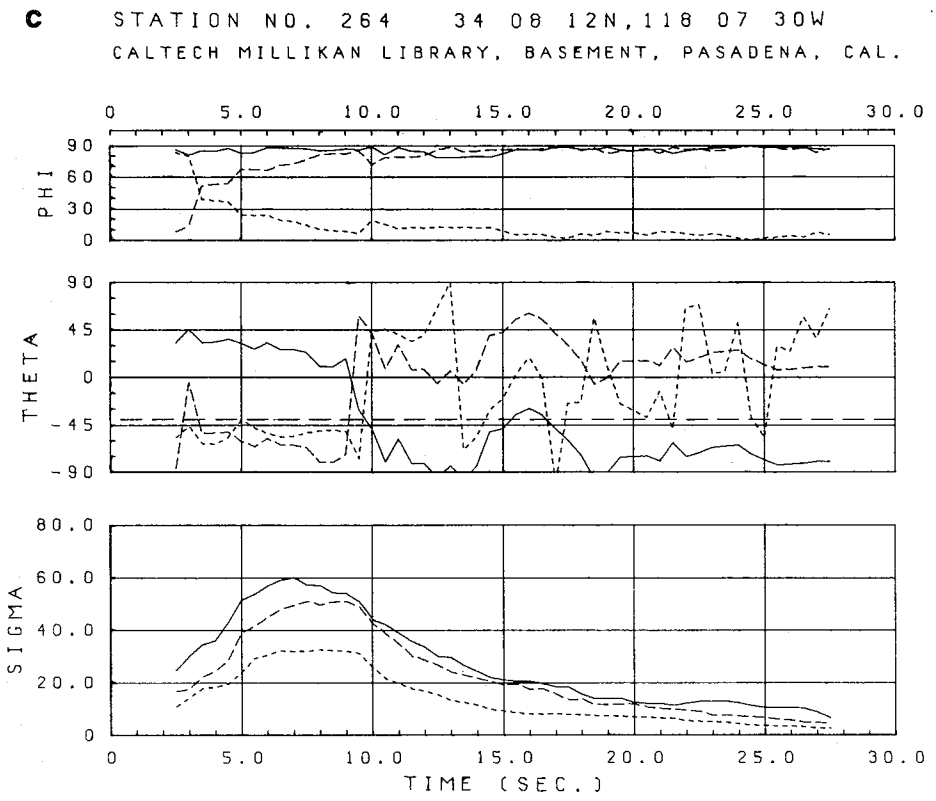


Fig. 3.3 Time dependent directions of principal axes and square root of principal variances in area A.



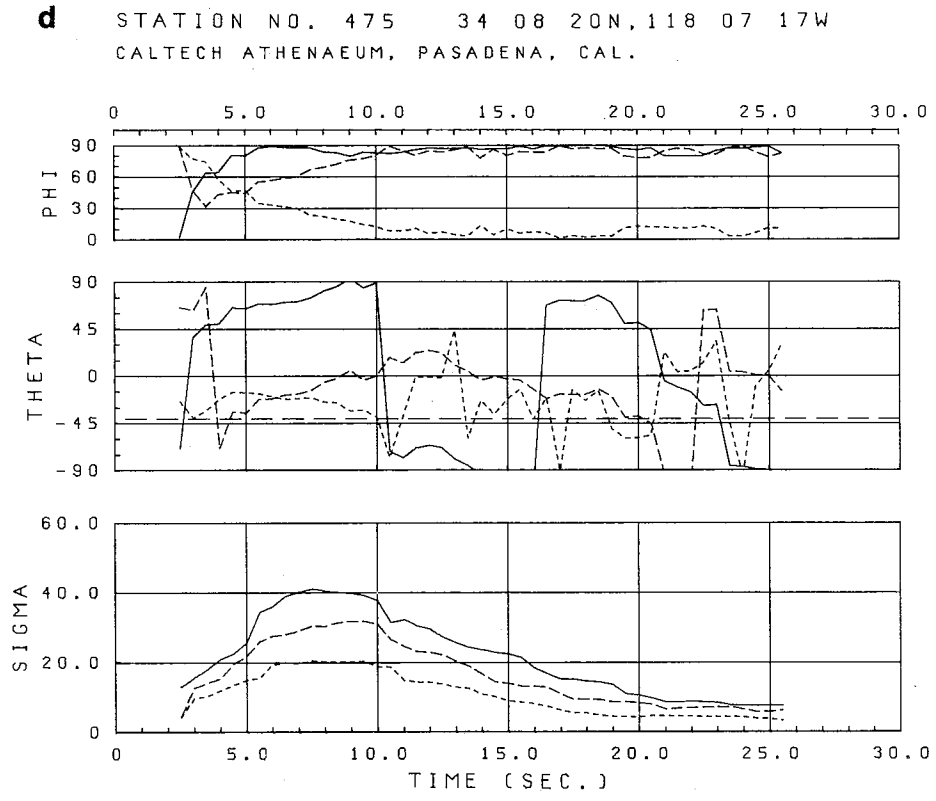


Fig. 3.3 (continued)

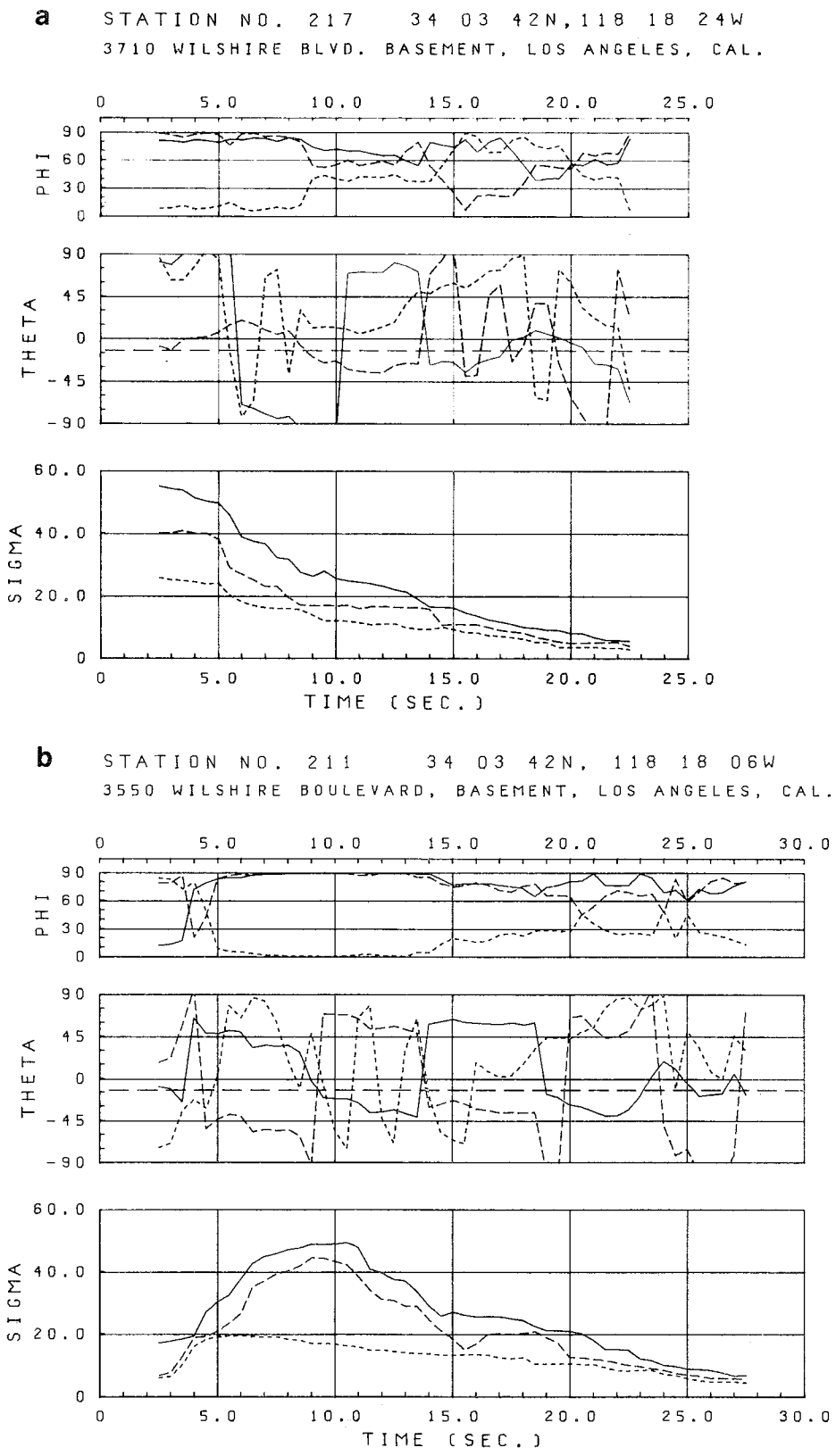
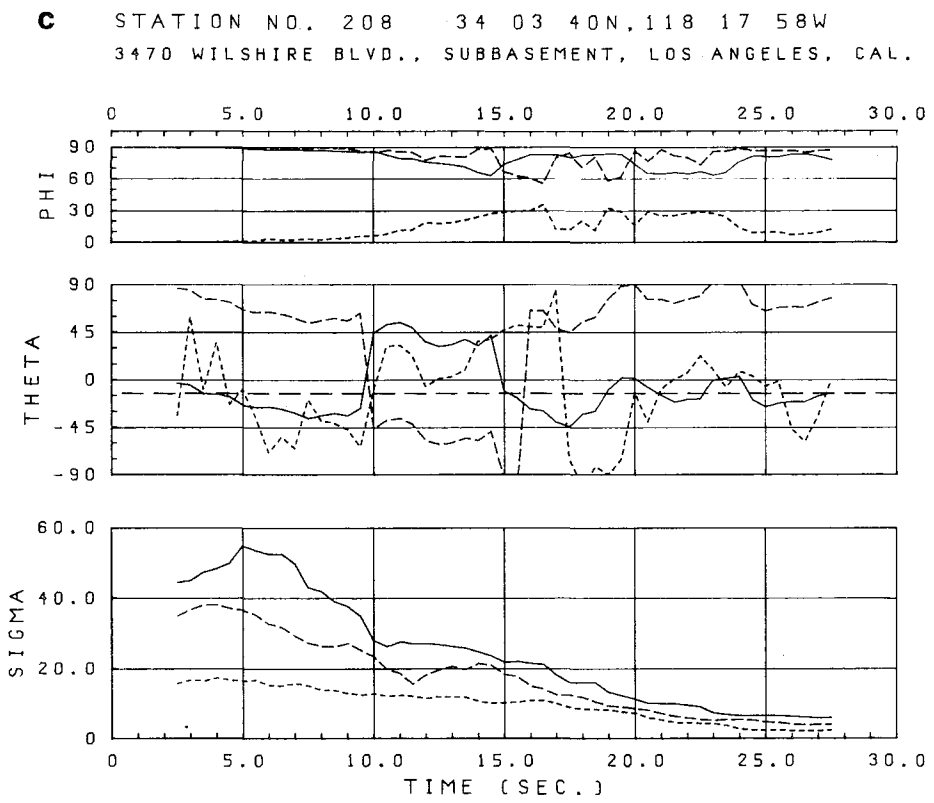


Fig. 3.4 Time dependent directions of principal axes and square root of principal variances in area B.



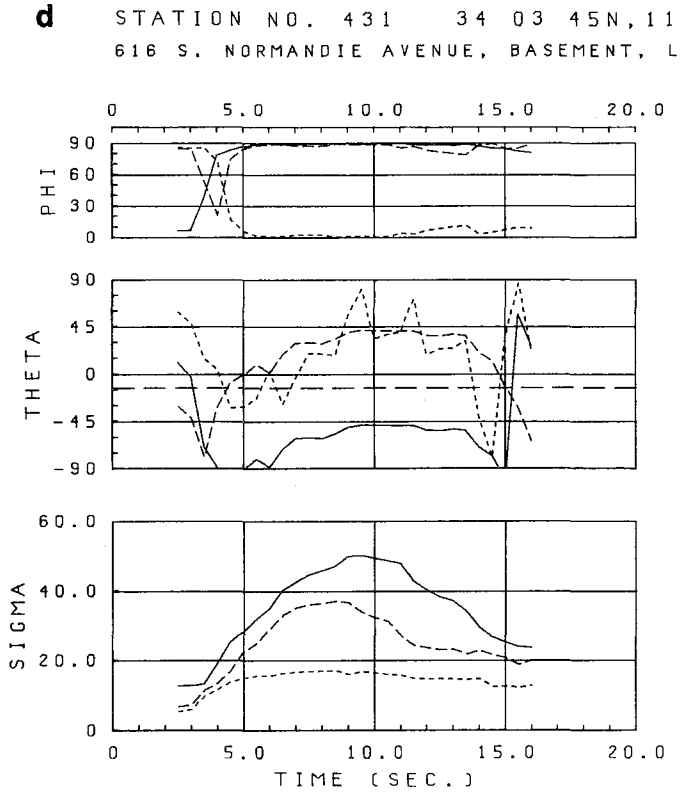
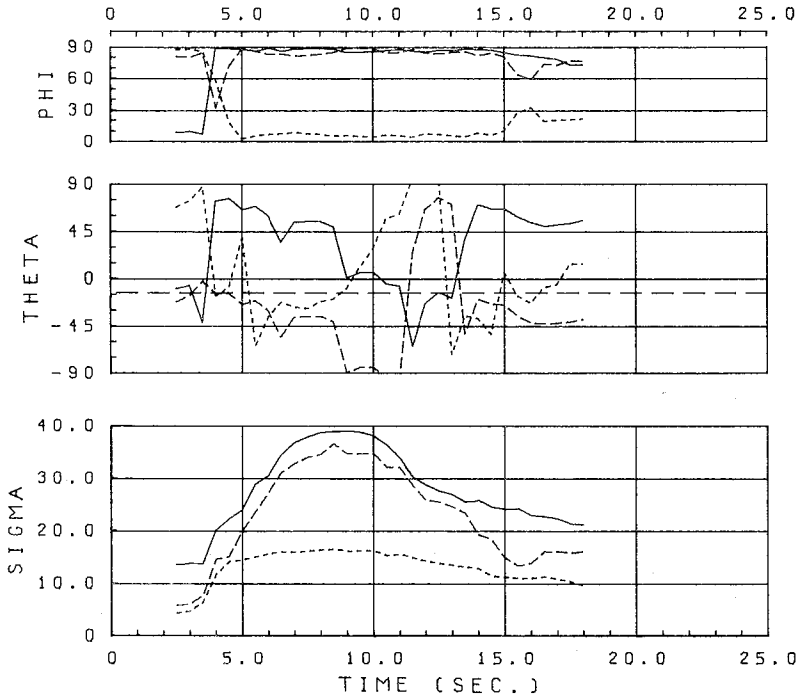


Fig. 3.4 (continued)

e STATION NO. 202 34 03 45N, 118 17 57W
3411 WILSHIRE BOULEVARD, 5TH BASEMENT, LOS ANGELES, CAL.



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3345 WILSHIRE BOULEVARD, BASEMENT, LOS ANGELES, CAL.

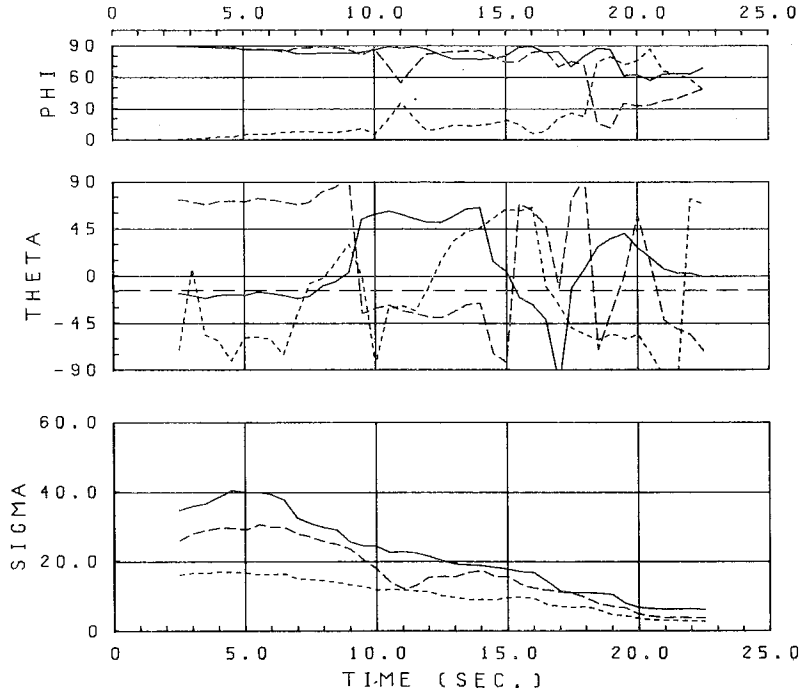
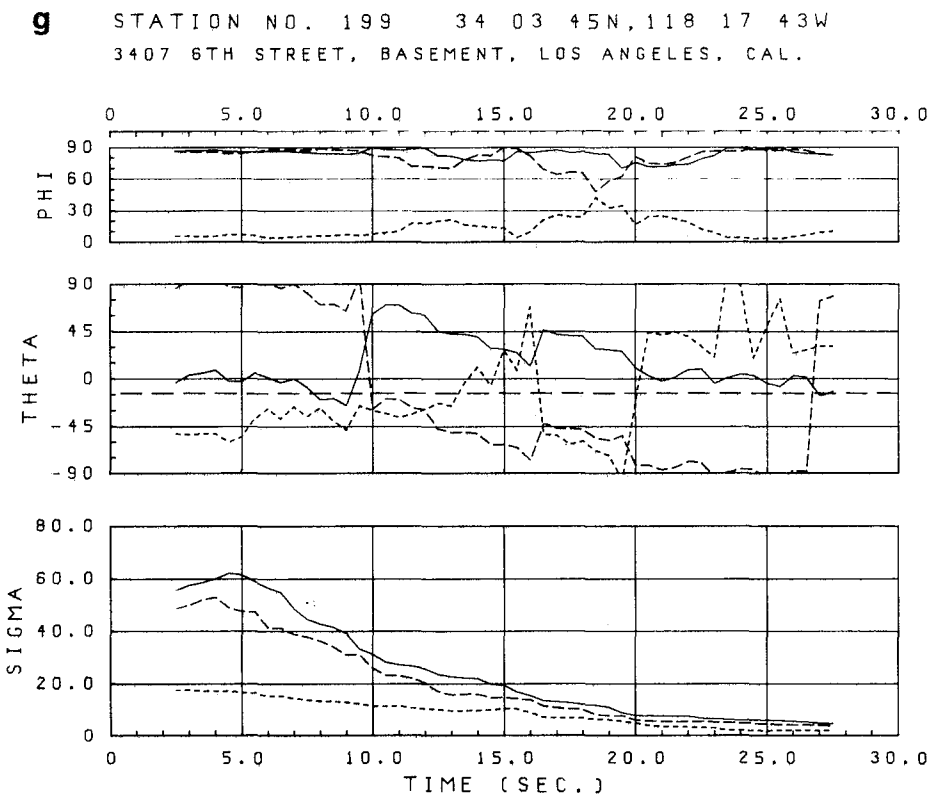


Fig. 3.4 (continued)



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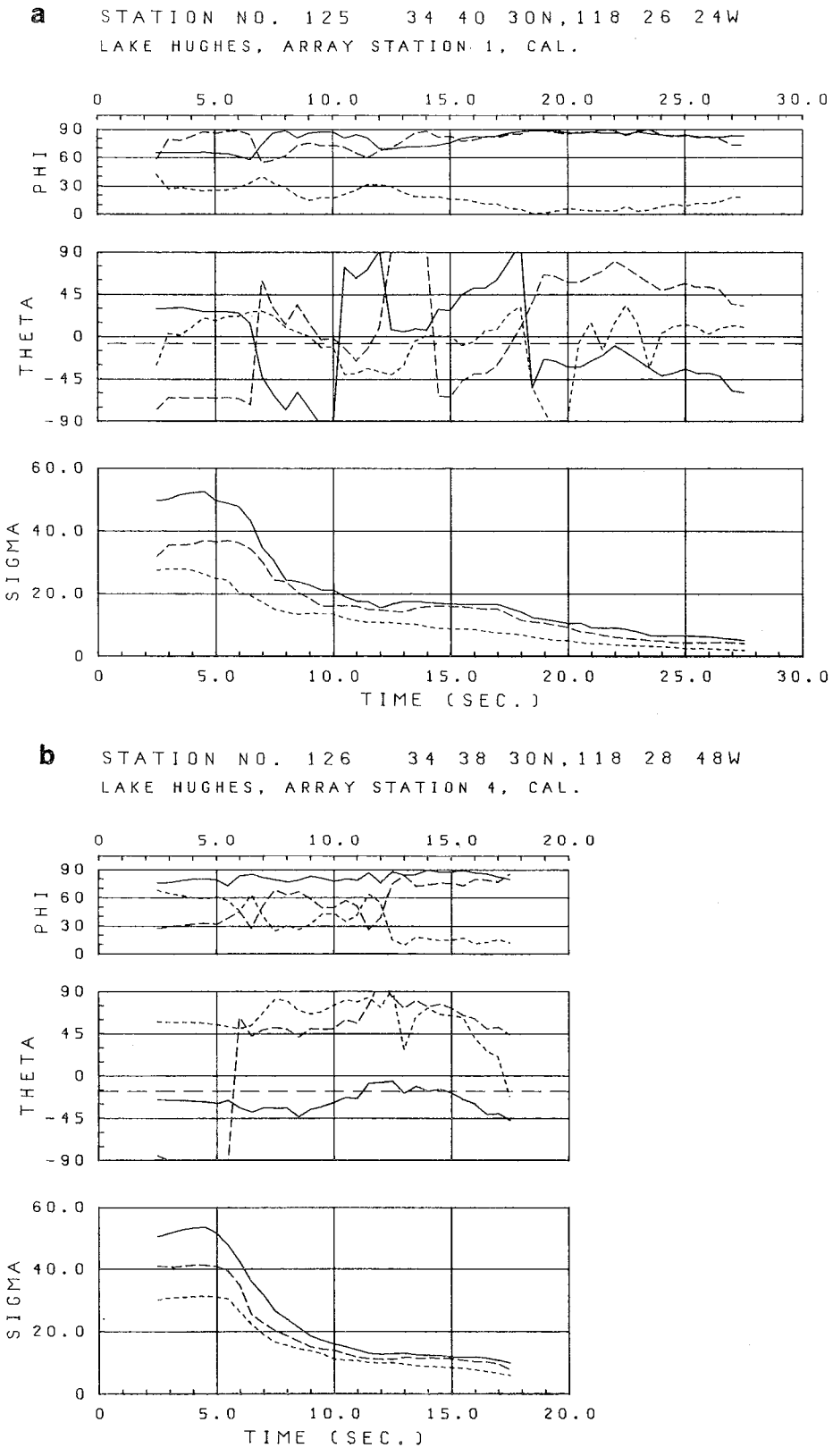
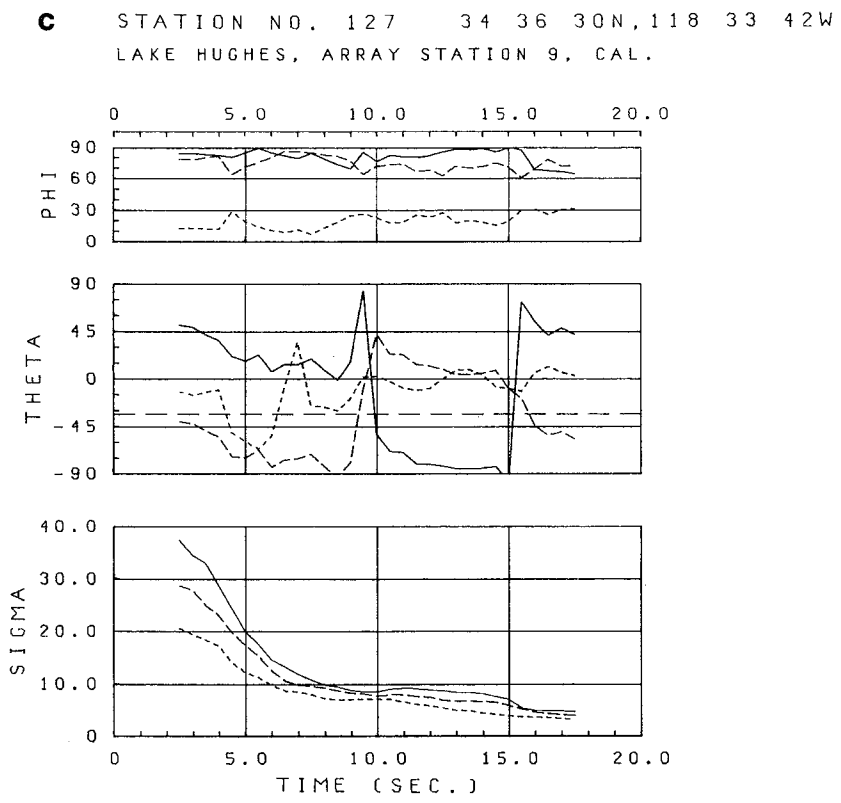
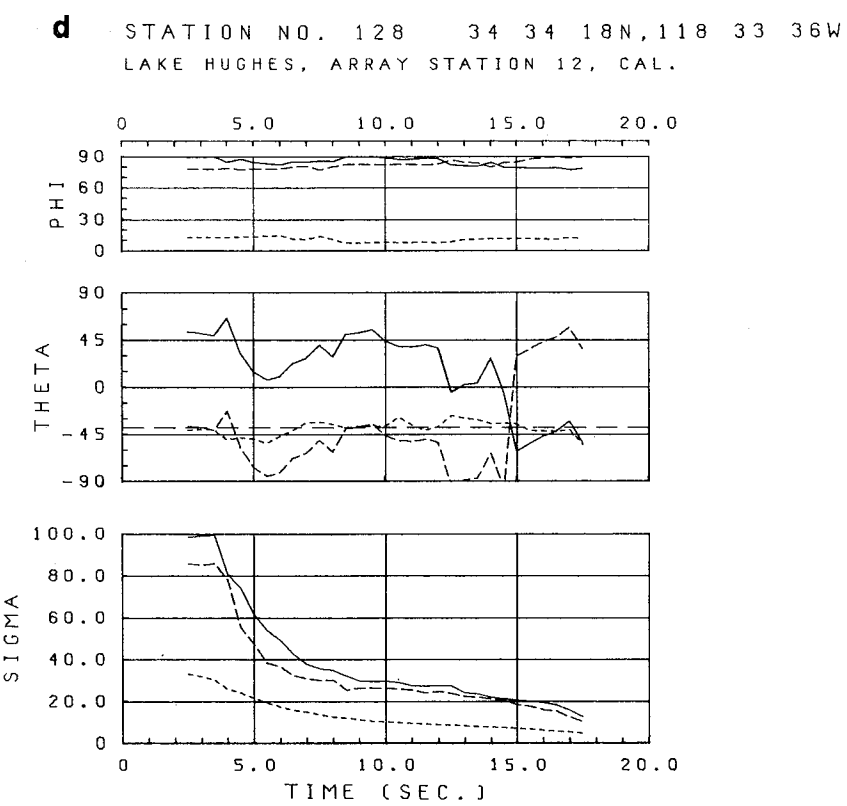


Fig. 3.5 Time dependent directions of principal axes and square root of principal variances in area C.





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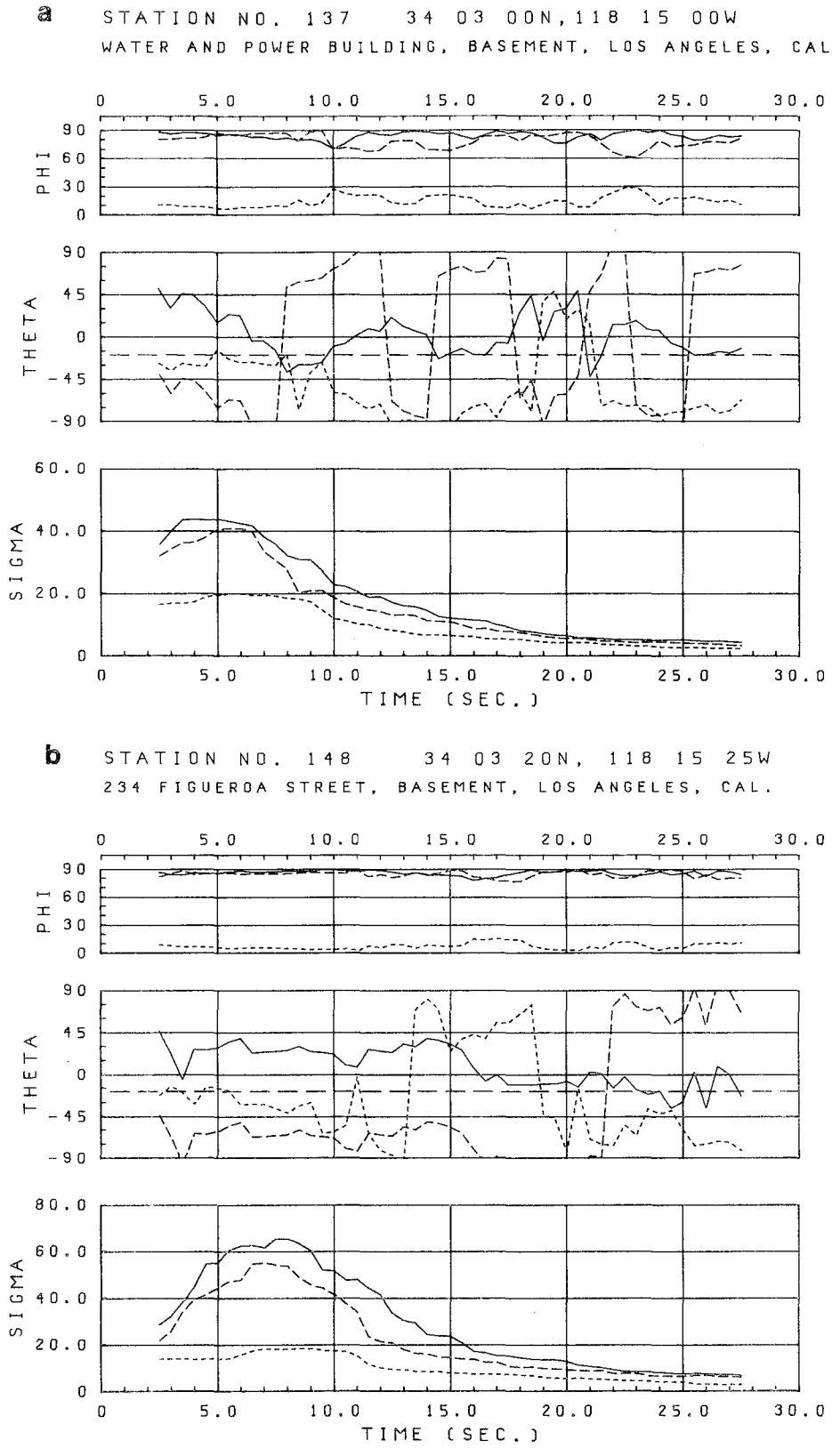
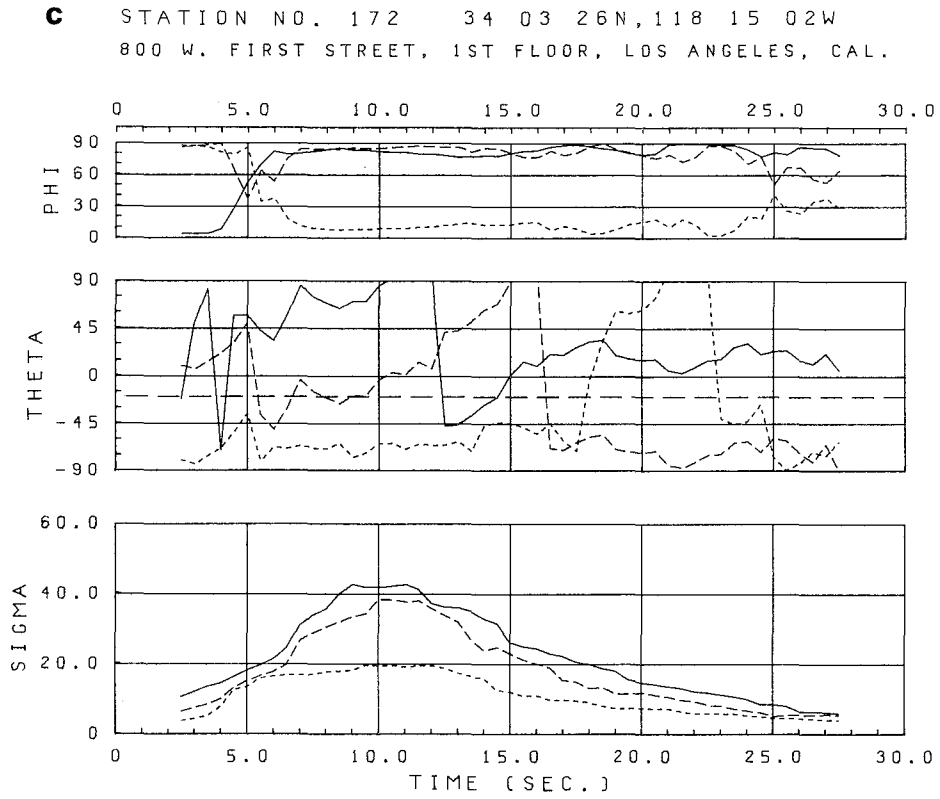


Fig. 3.6 Time dependent directions of principal axes and square root of principal variances in area D.



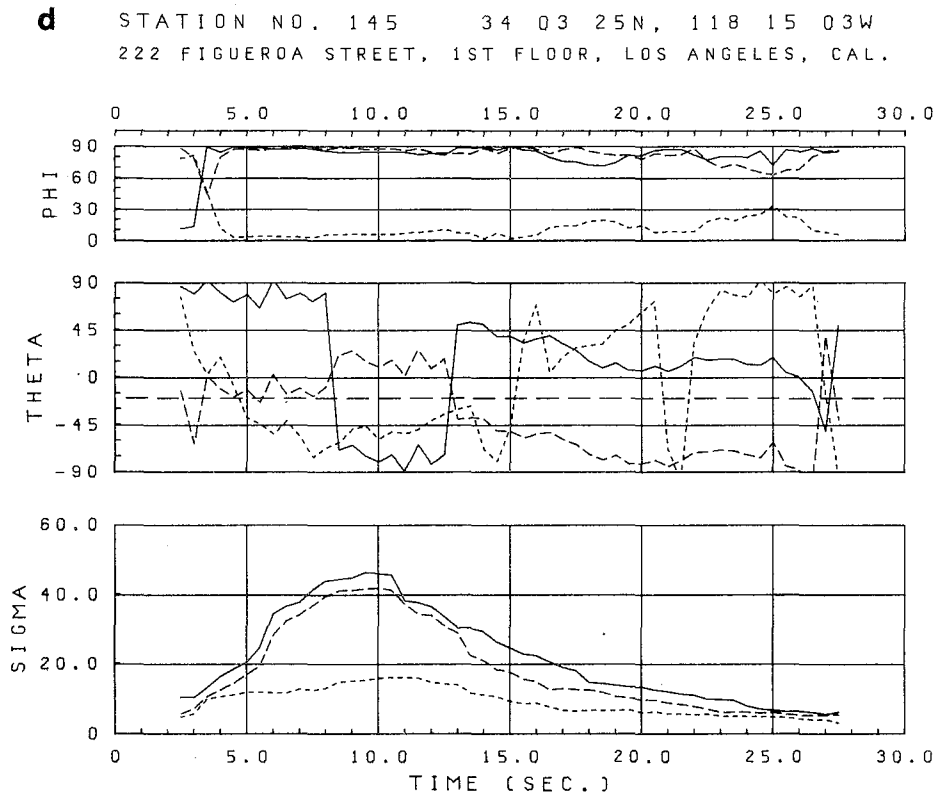


Fig. 3.6 (continued)

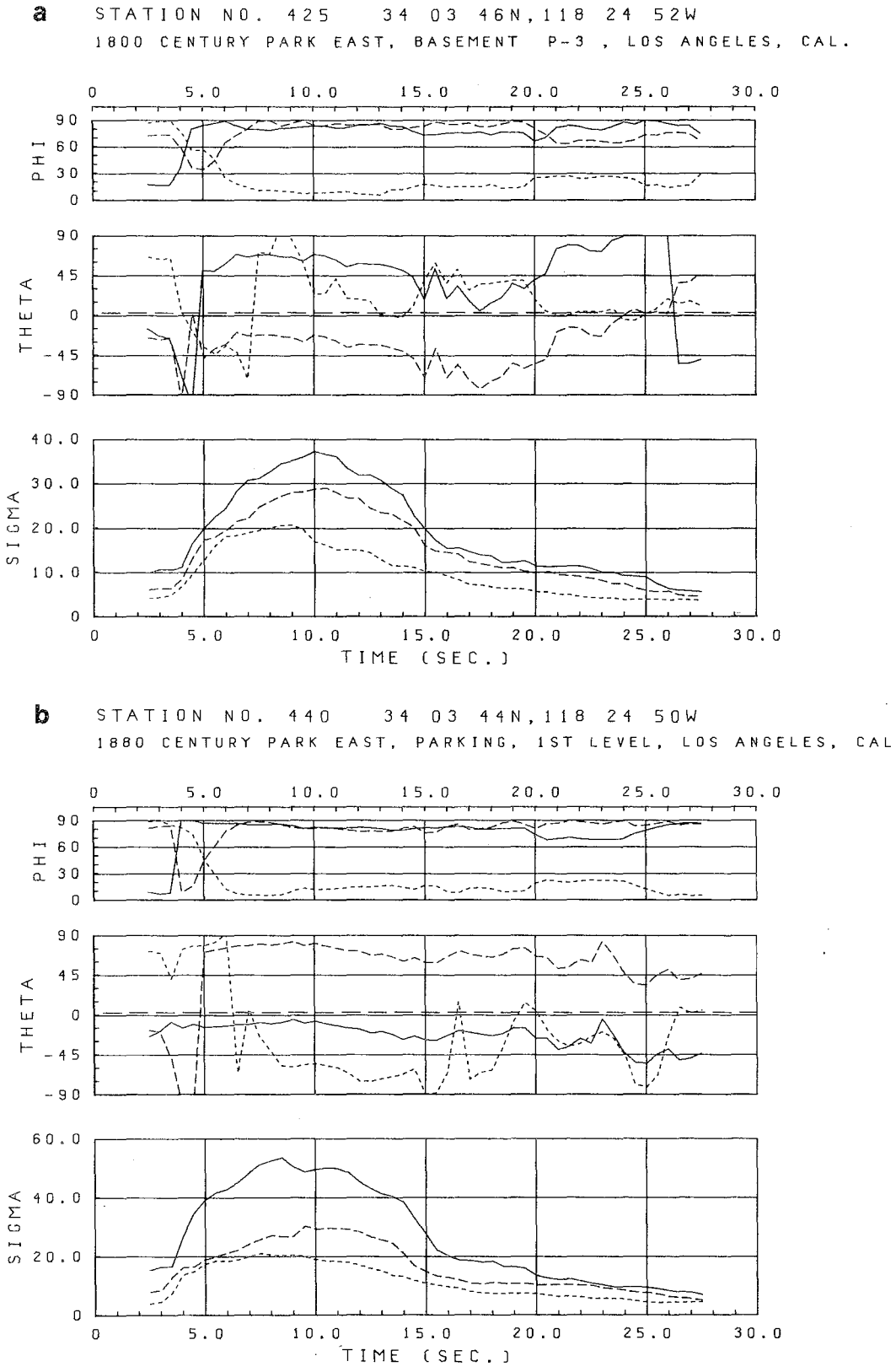
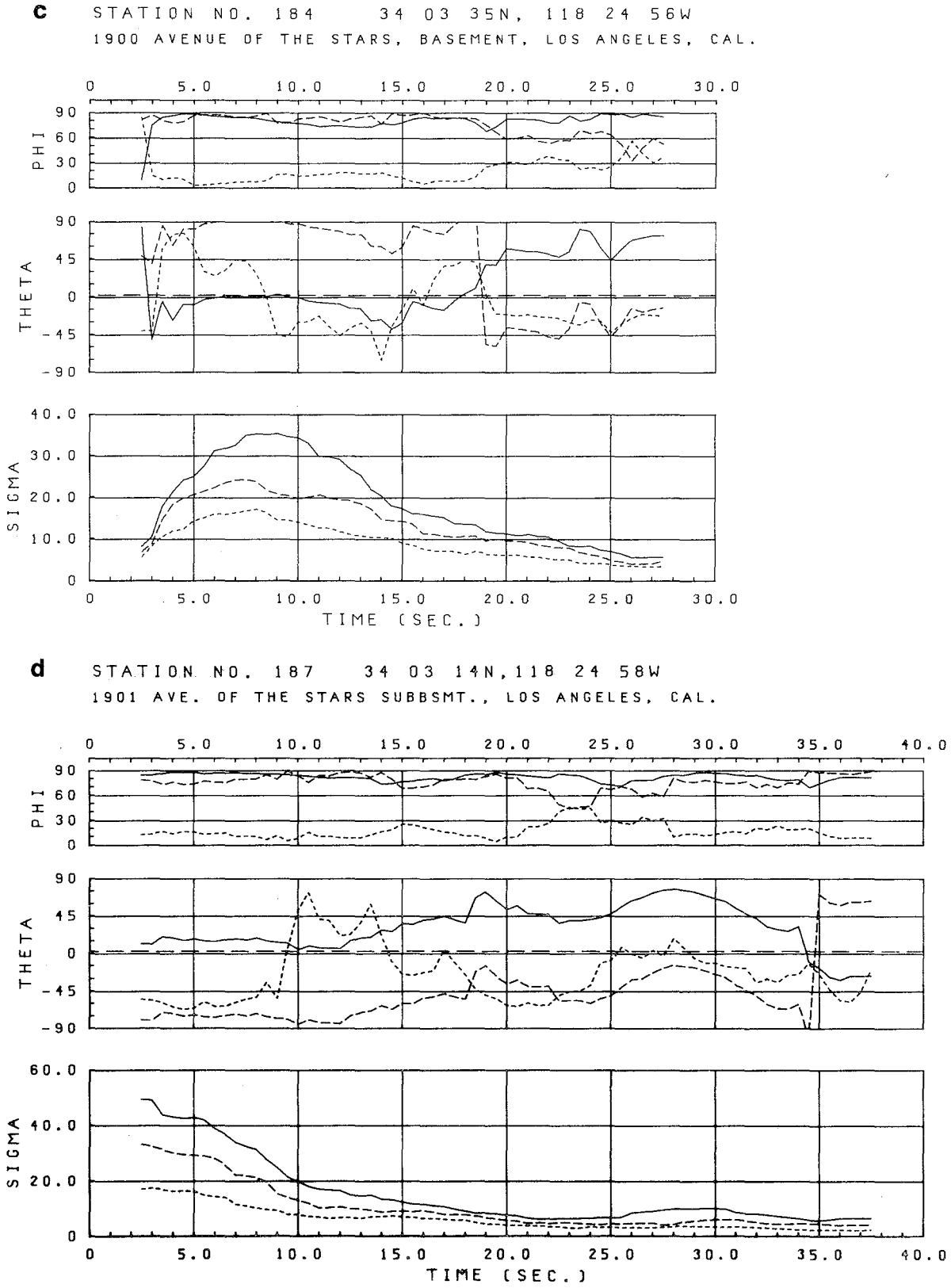


Fig. 3.7 Time dependent directions of principal axes and square root of principal variances in area E.



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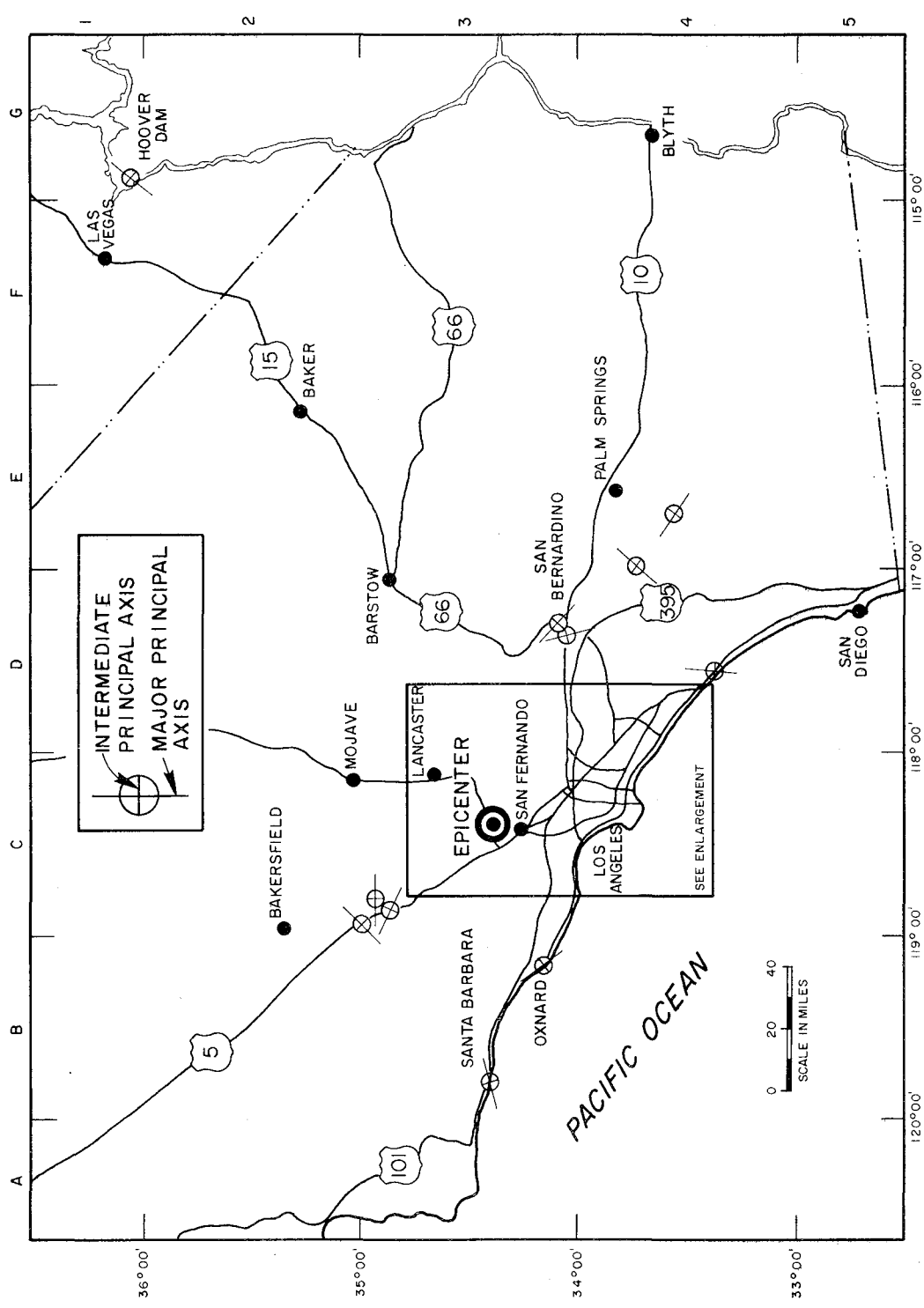


Fig. 3.8 Directions of major and intermediate principal axes of stations in central and southern California.

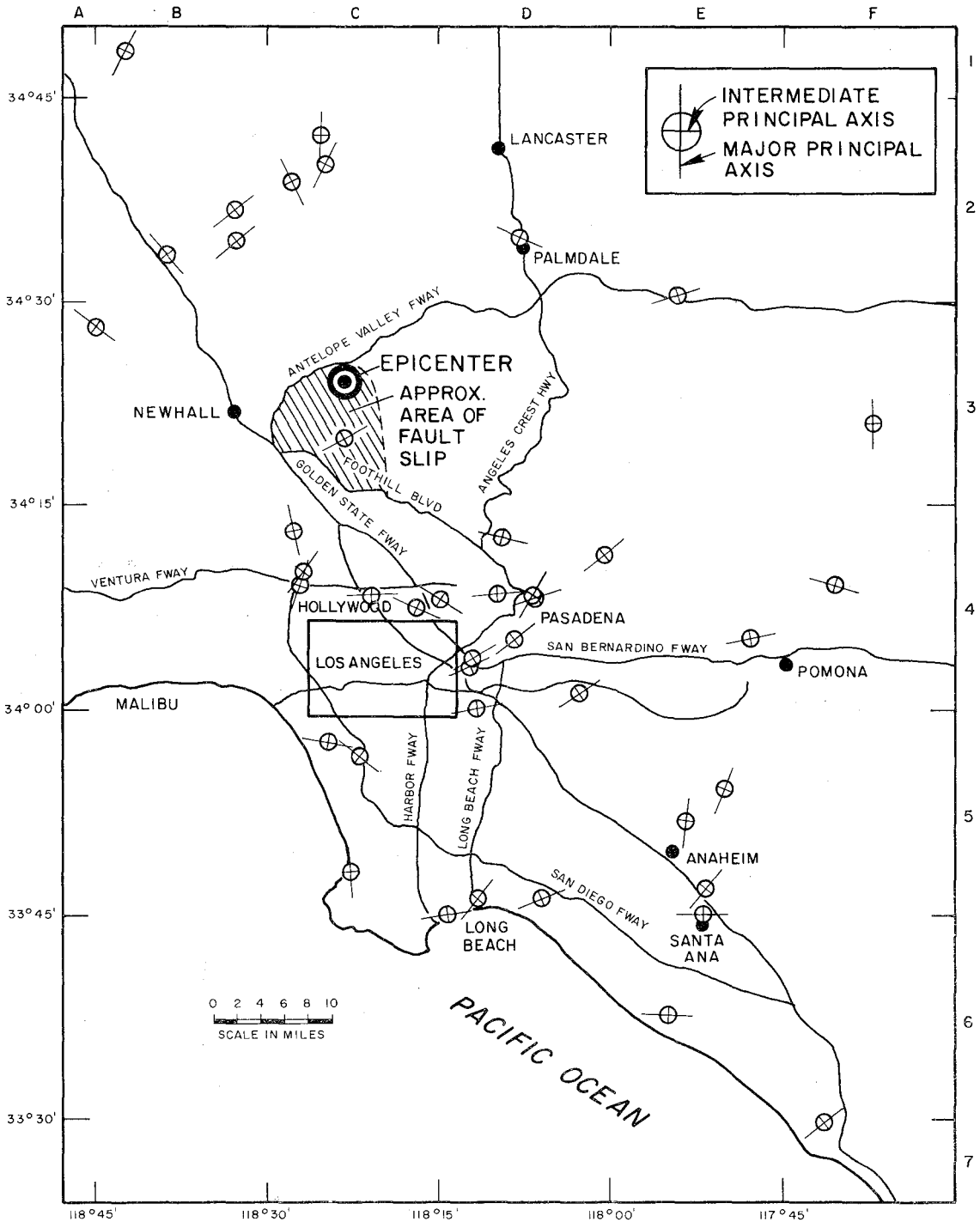


Fig. 3.9 Directions of major and intermediate principal axes of stations in extended Los Angeles area.

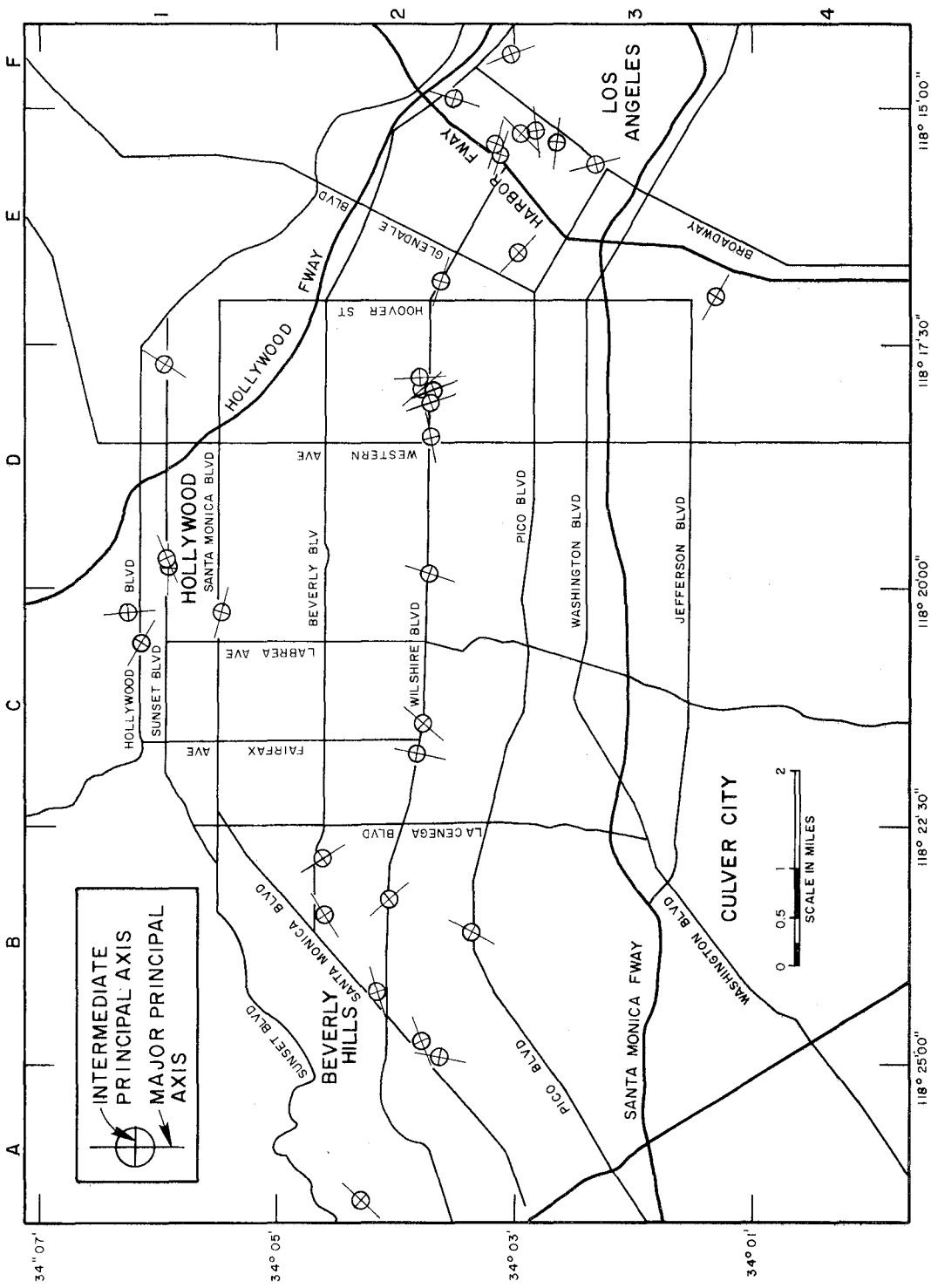


Fig. 3.10 Directions of major and intermediate principal axes of stations in central Los Angeles.

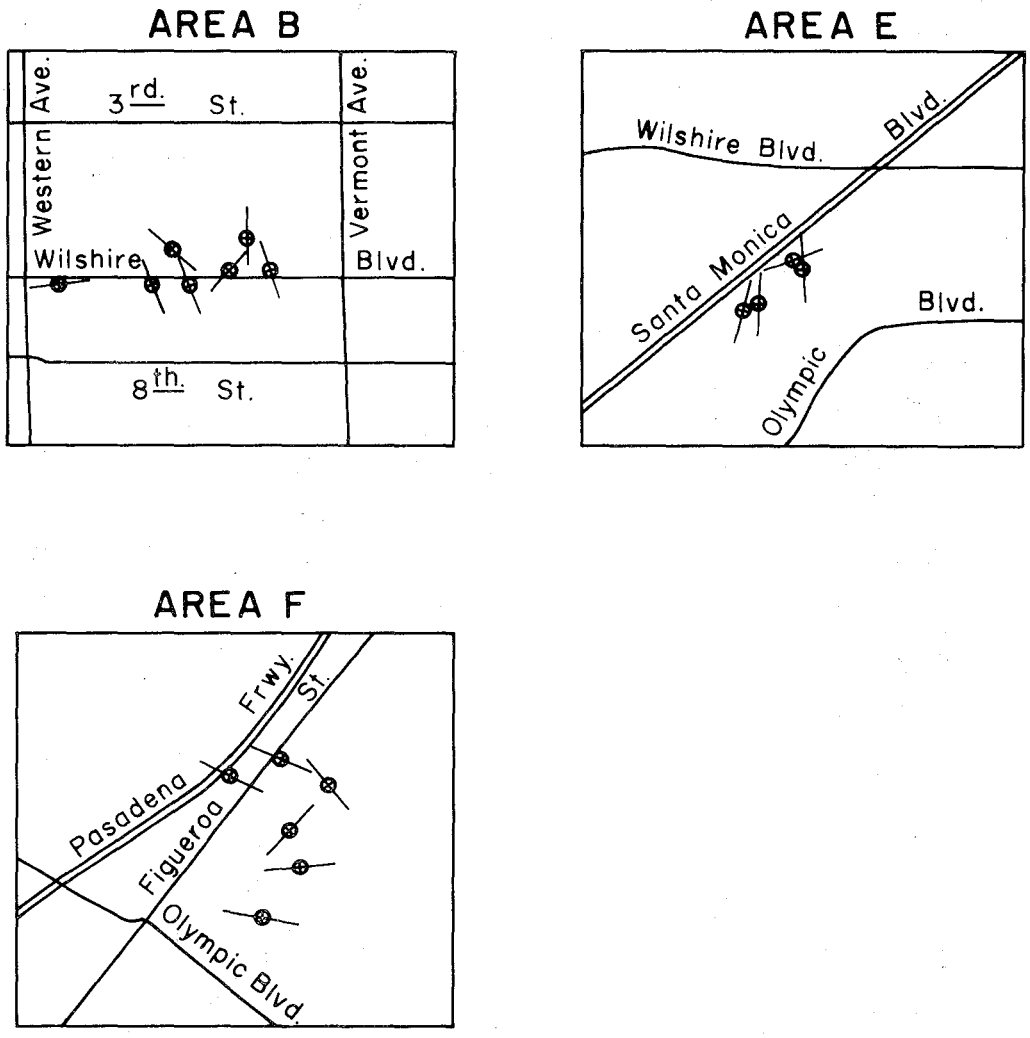


Fig. 3.11 Directions of major and intermediate principal axes of stations along Wilshire Boulevard, Santa Monica Boulevard and Figueroa Street.

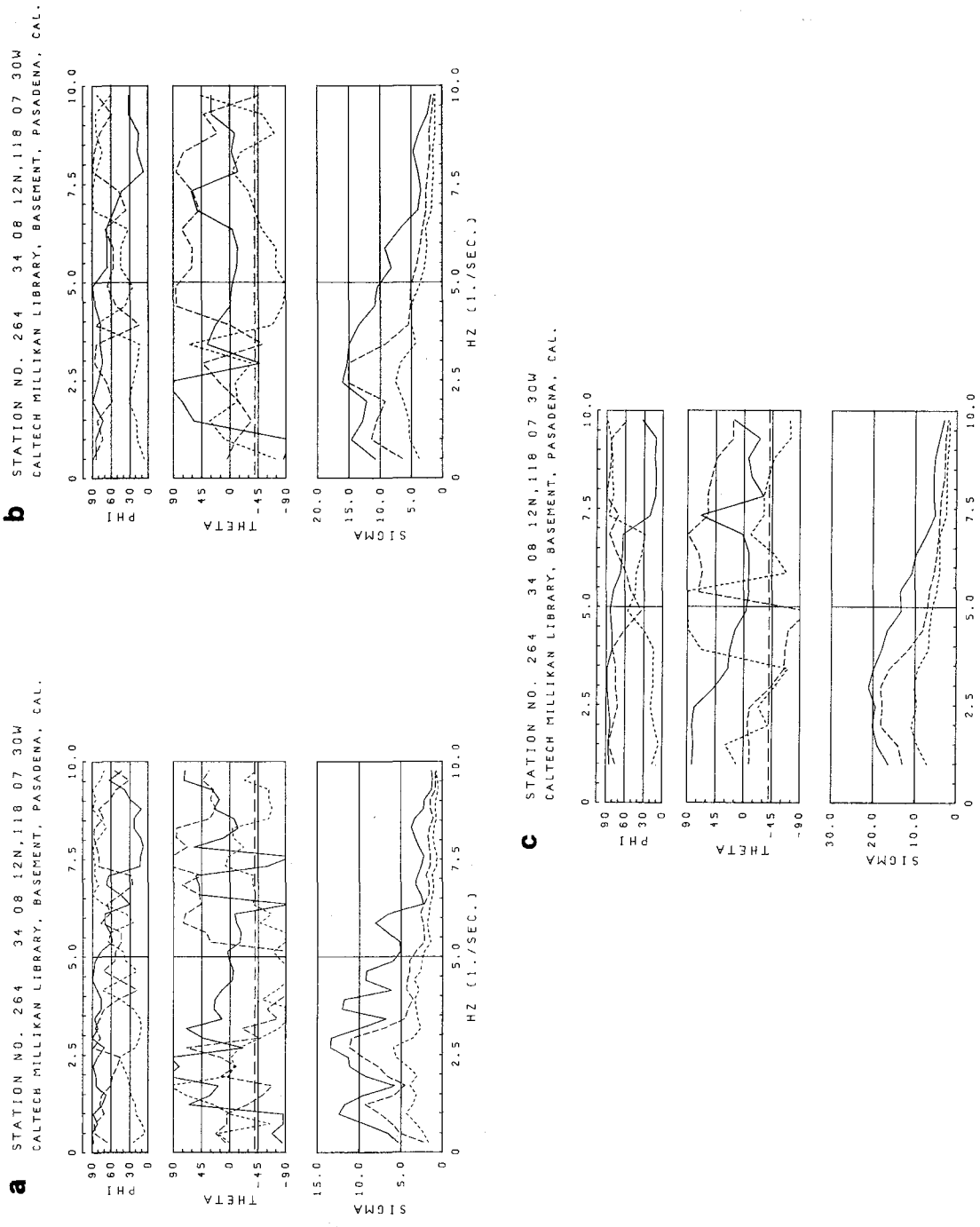


Fig. 3.12 Frequency dependent directions of principal axes and square root of principal variances at station No. 264.

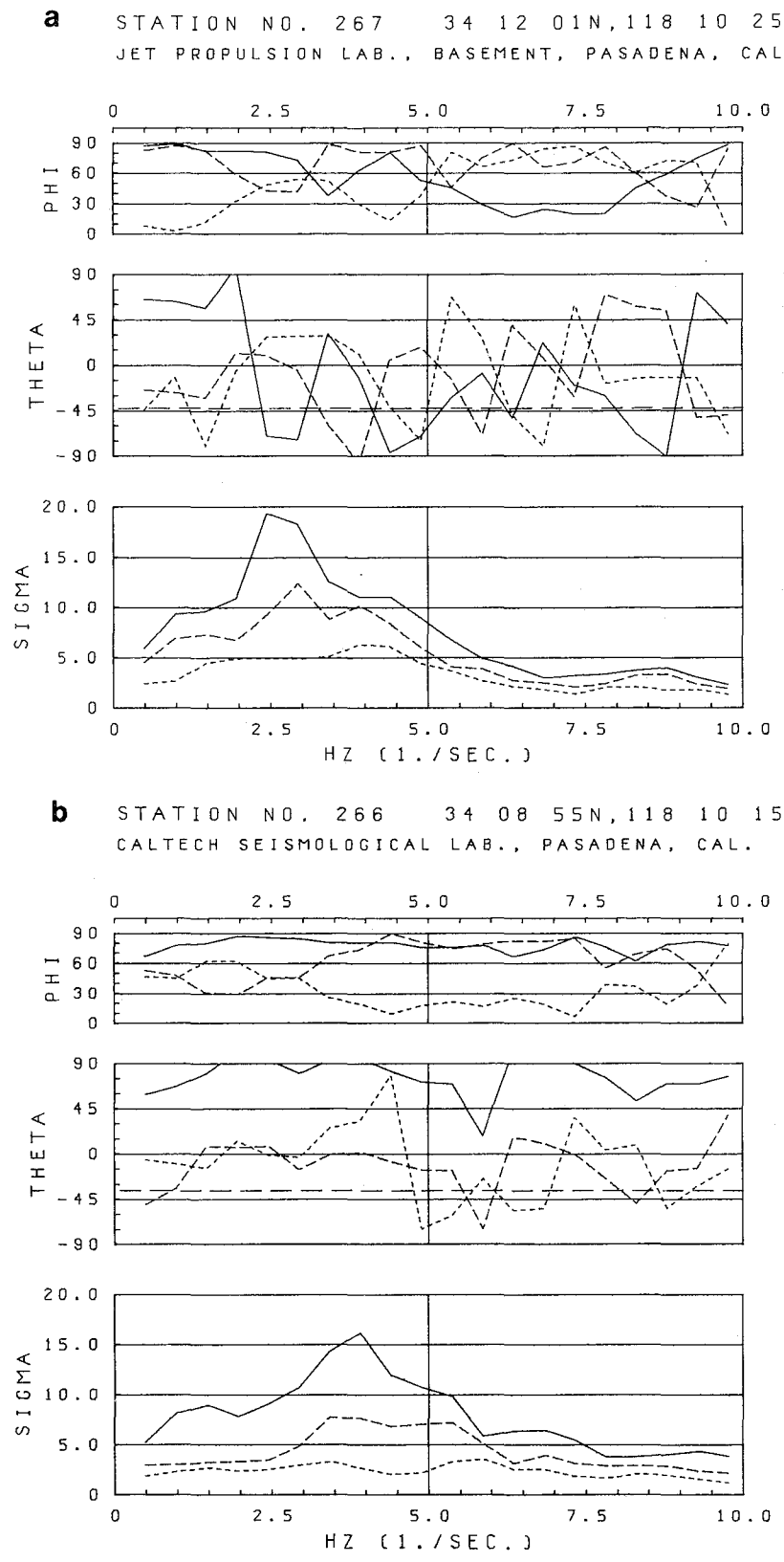


Fig. 3.13 Frequency dependent directions of principal axes and square root of principal variances in area A.

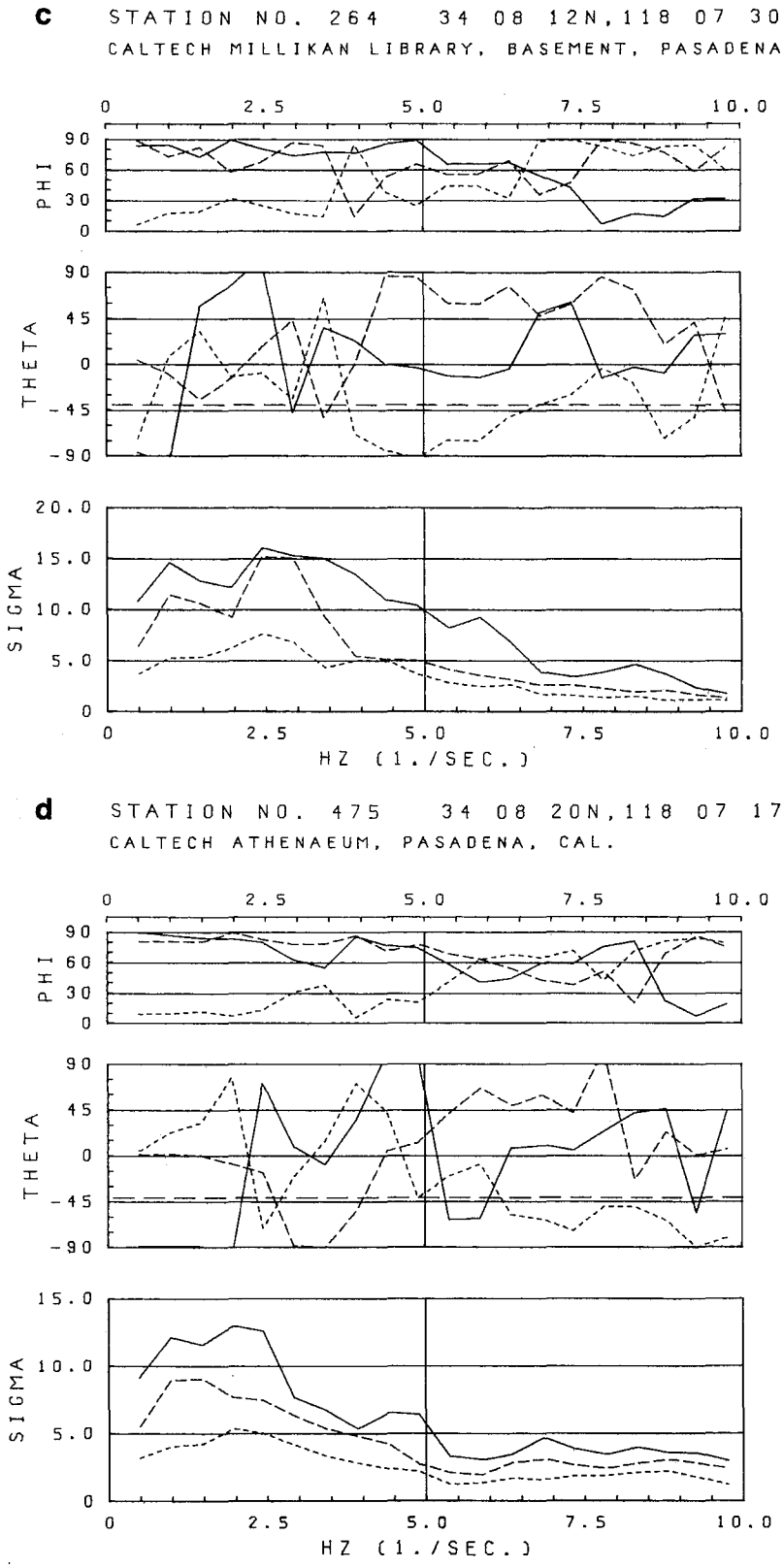


Fig. 3.13 (continued)

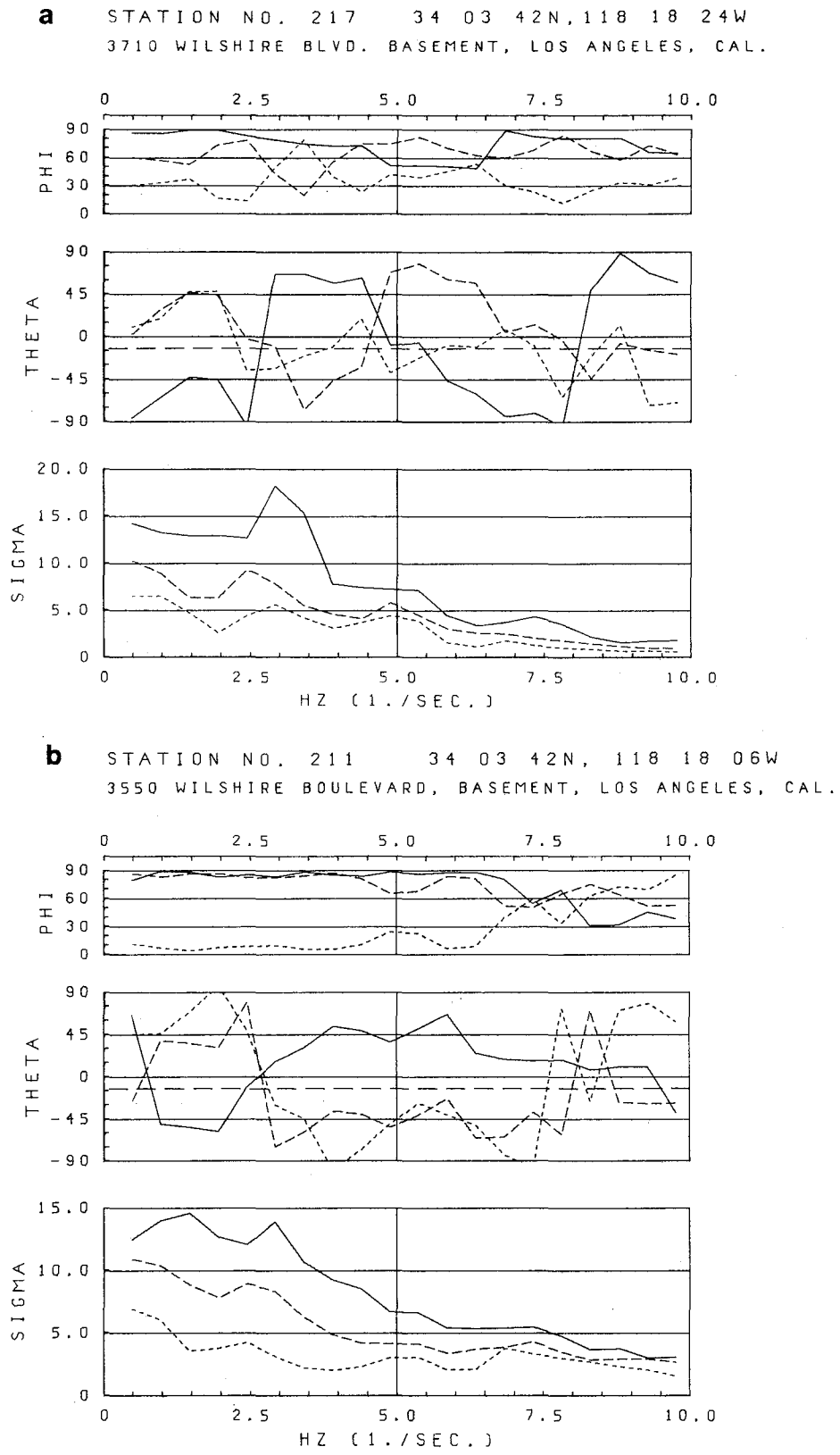


Fig. 3.14 Frequency dependent directions of principal axes and square root of principal variances in area B.

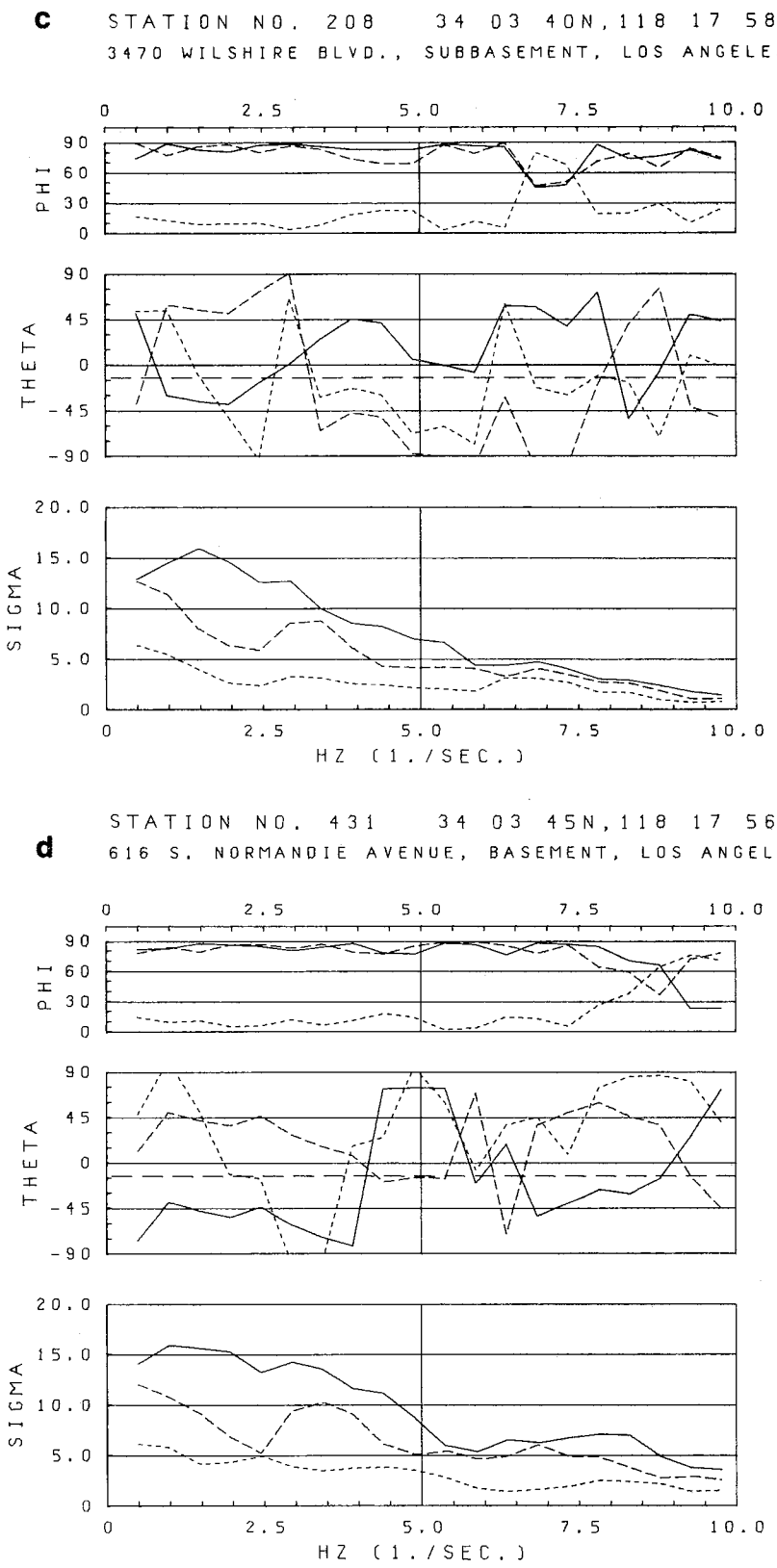
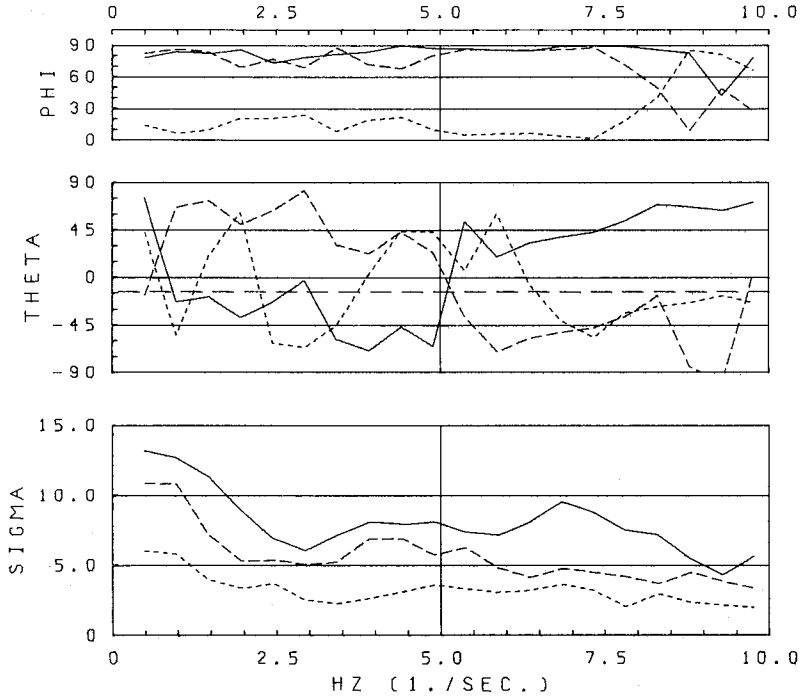


Fig. 3.14 (continued)

e STATION NO. 202 34 03 45N, 118 17 57W

3411 WILSHIRE BOULEVARD, 5TH BASEMENT, LOS ANGELES, CAL.



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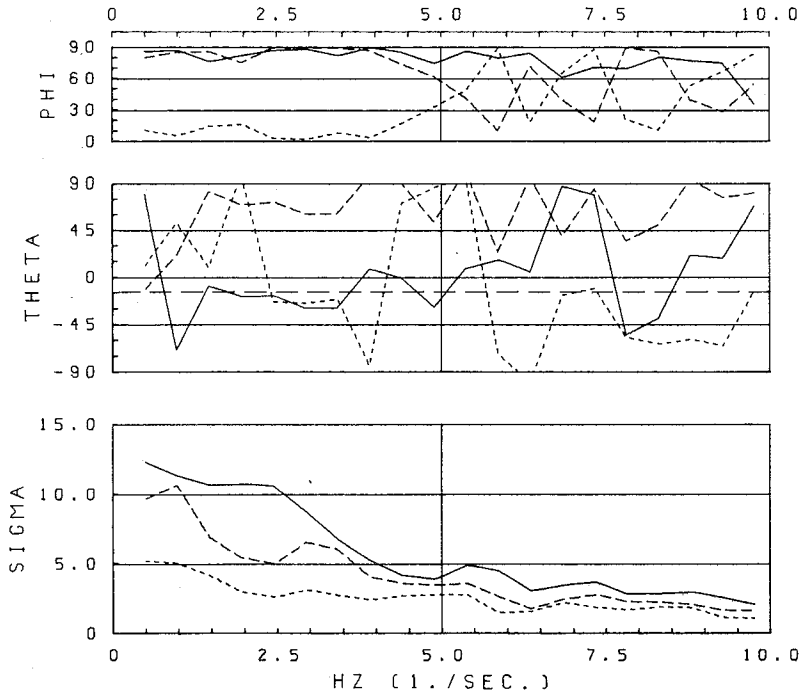
3345 WILSHIRE BOULEVARD, BASEMENT, LOS ANGELES, CAL.



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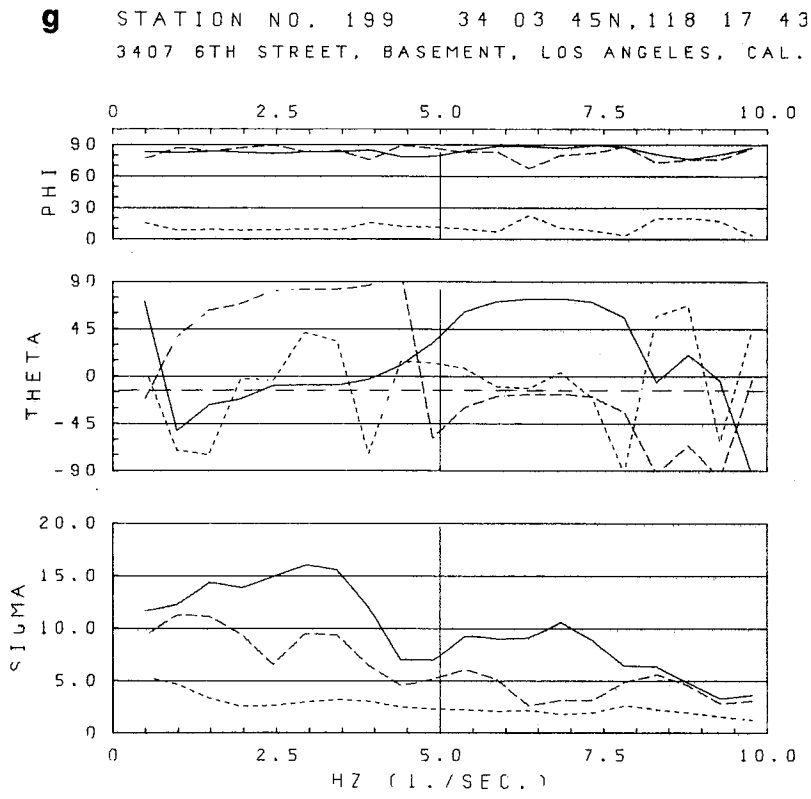

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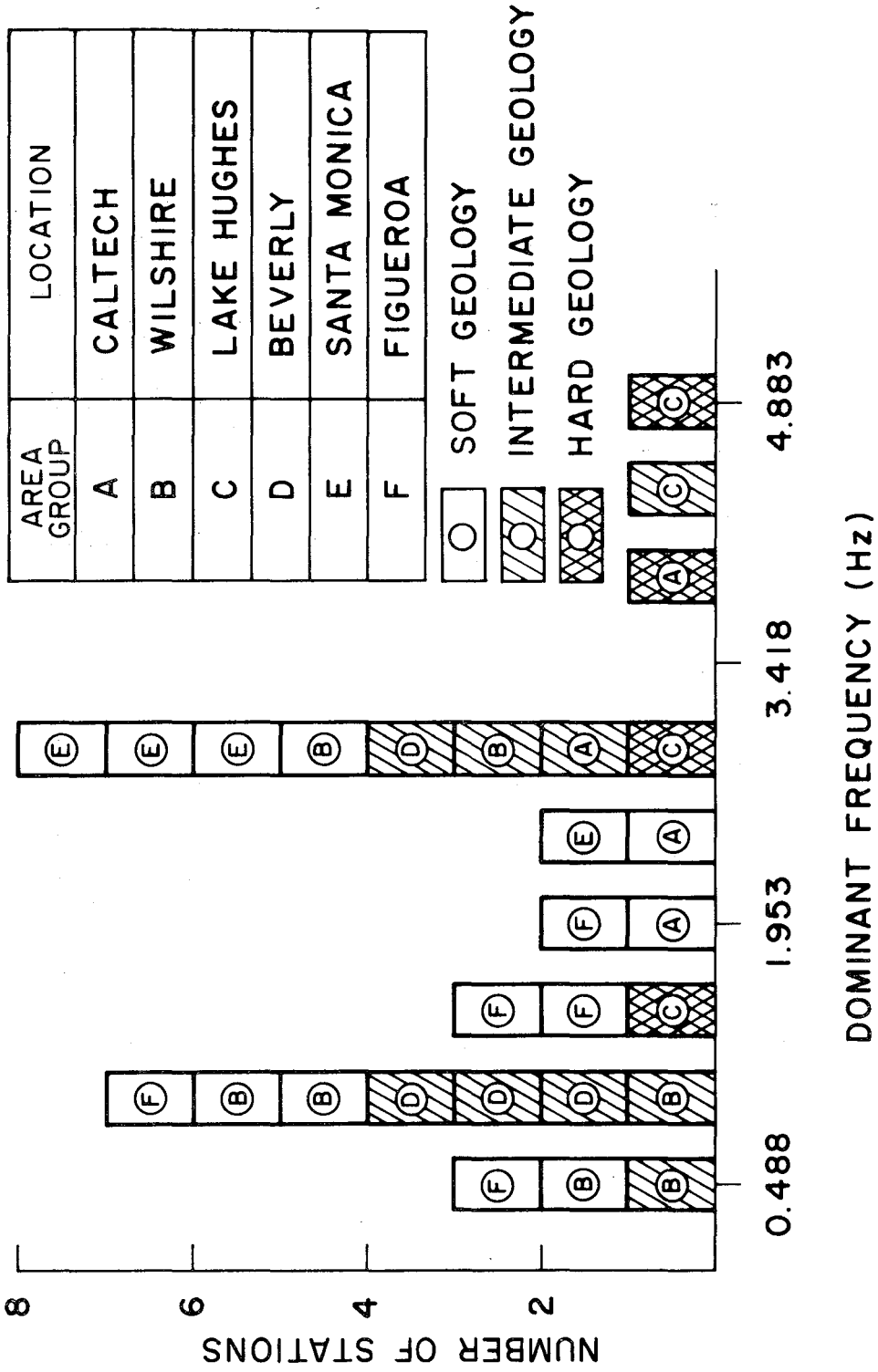


Fig. 3.15 Correlation of dominant frequency with soil classification.

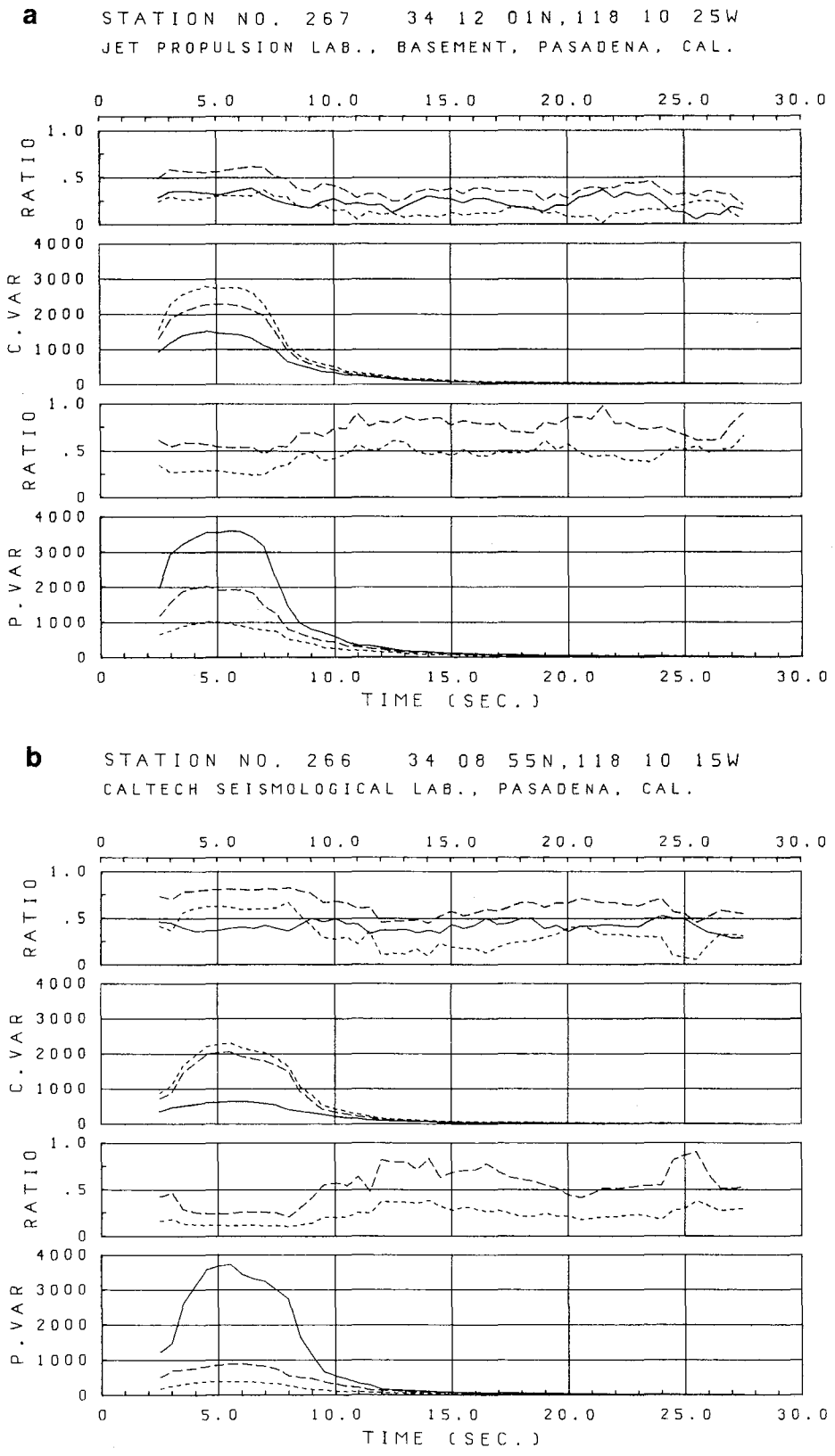
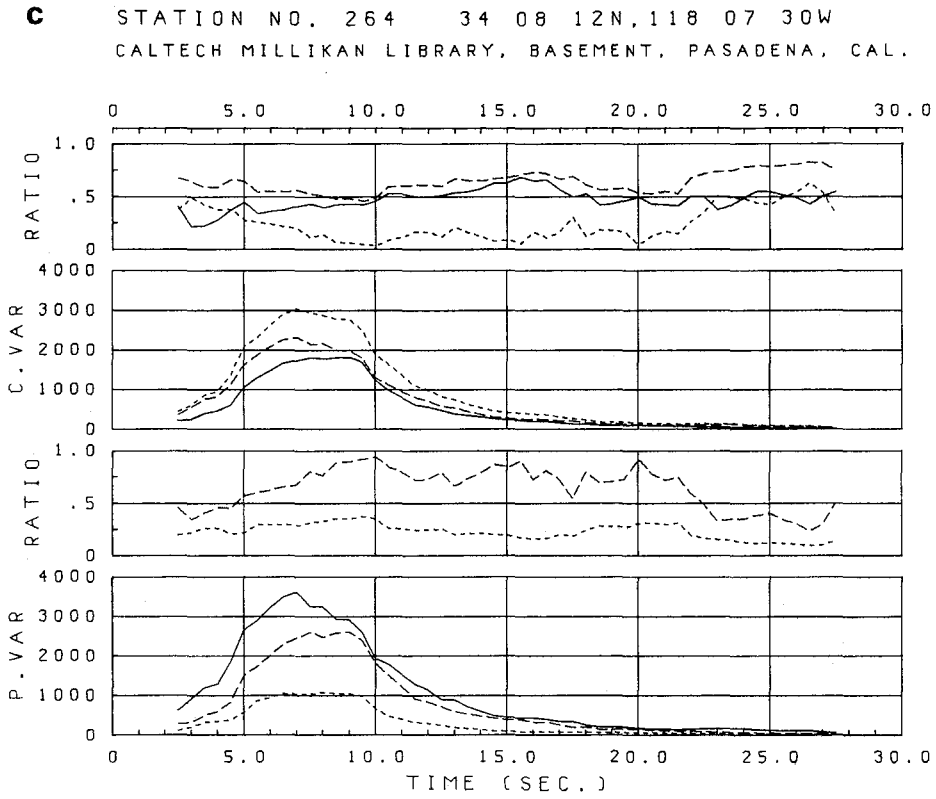
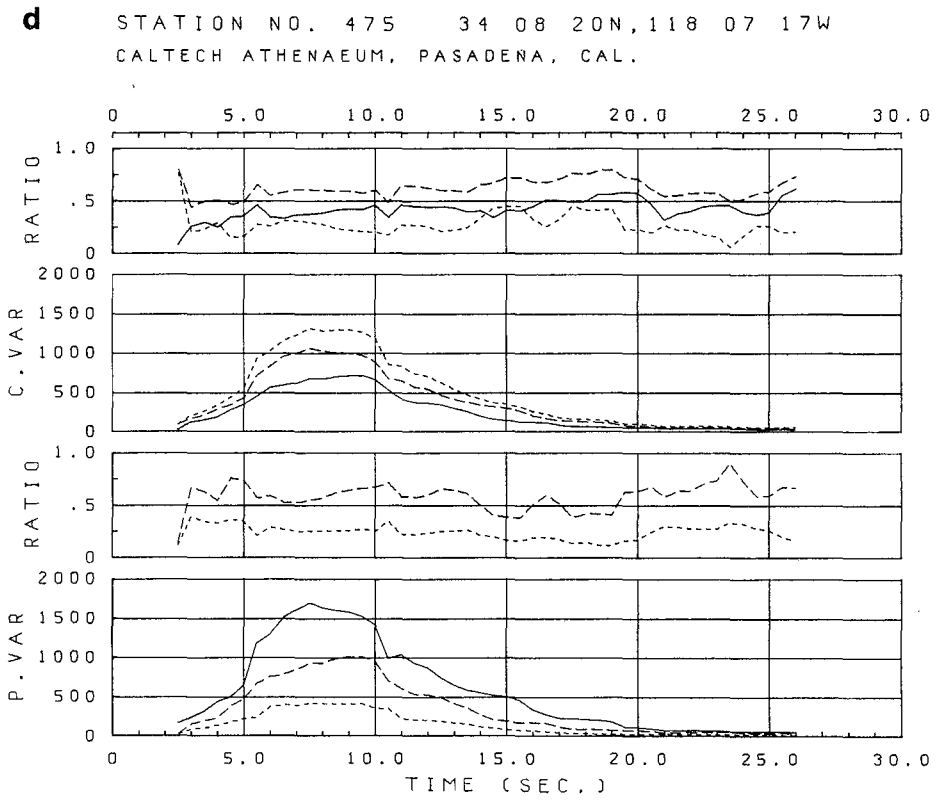


Fig. 3.16 Time dependent principal variances and principal cross correlation coefficients in area A.





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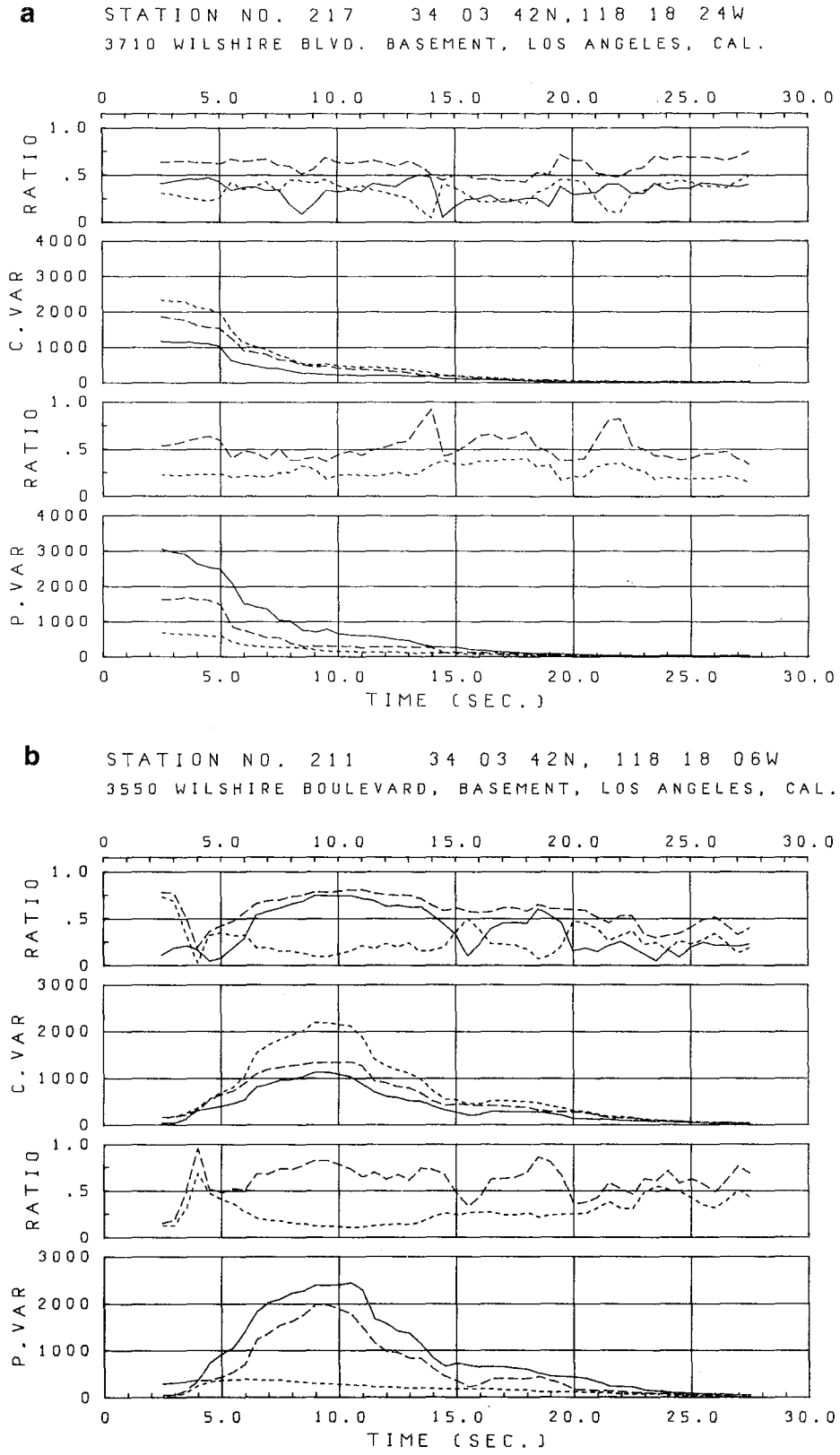
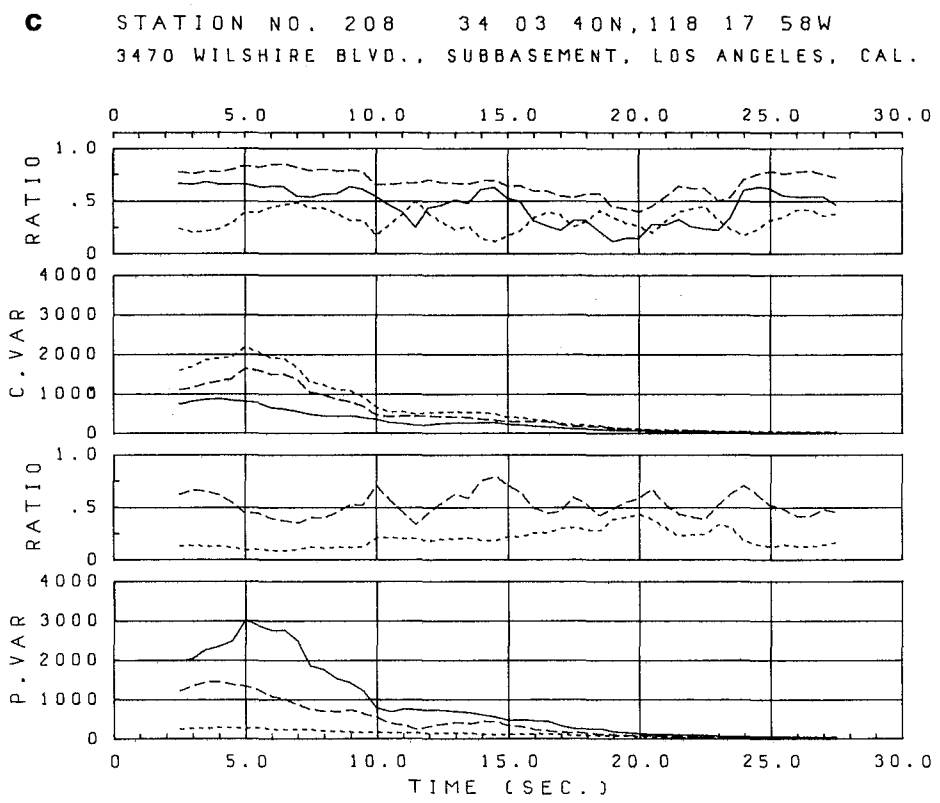
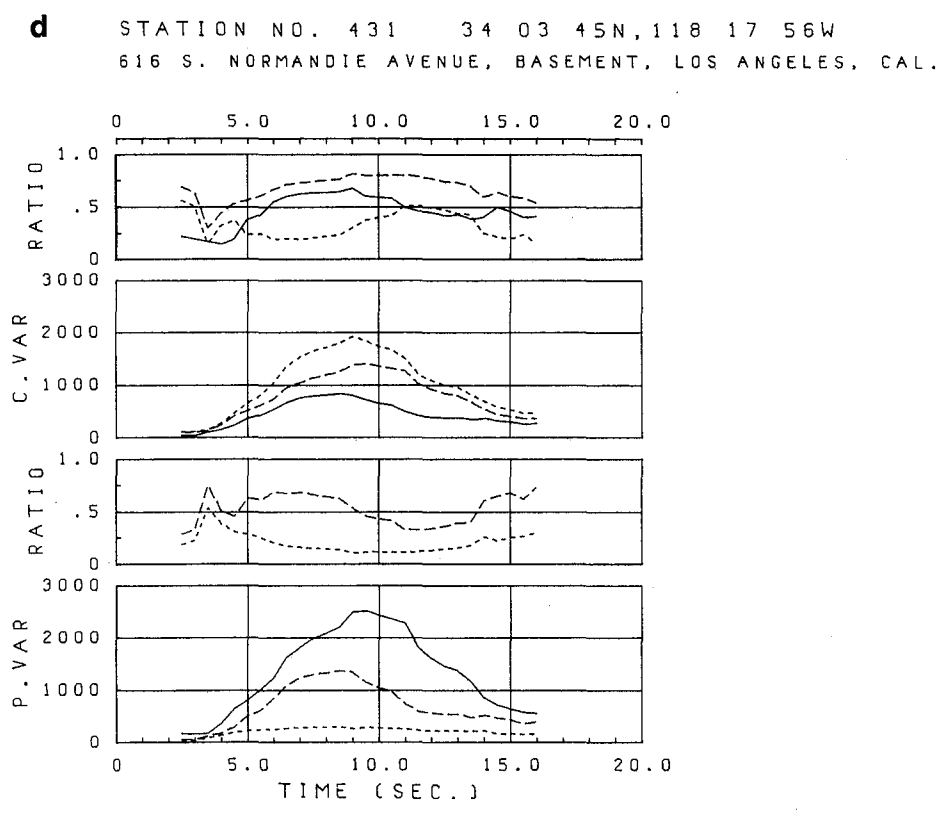


Fig. 3.17 Time dependent principal variances and principal cross correlation coefficients in area B.





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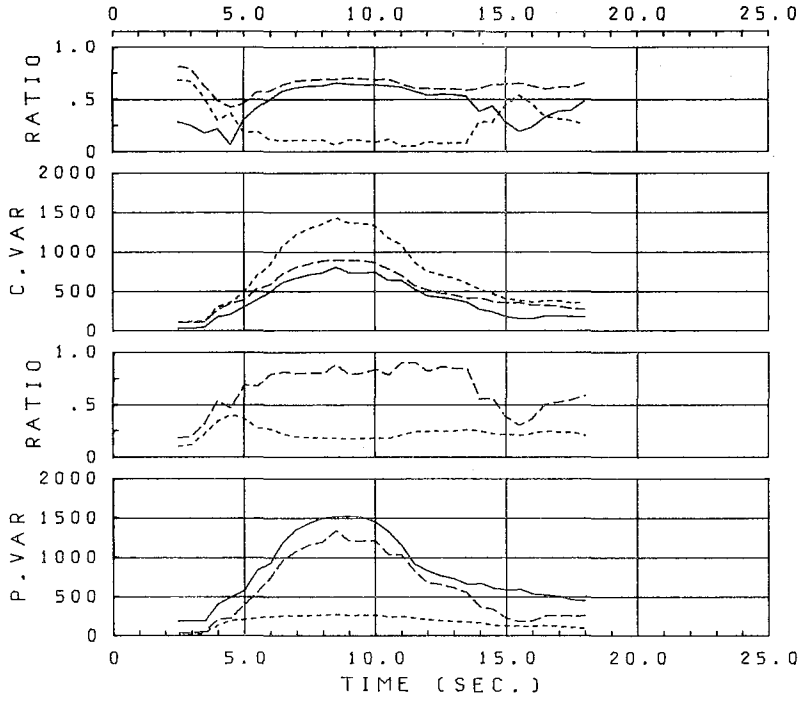
e STATION NO. 202 34 03 45N, 118 17 57W

3411 WILSHIRE BOULEVARD, 5TH BASEMENT, LOS ANGELES, CAL.



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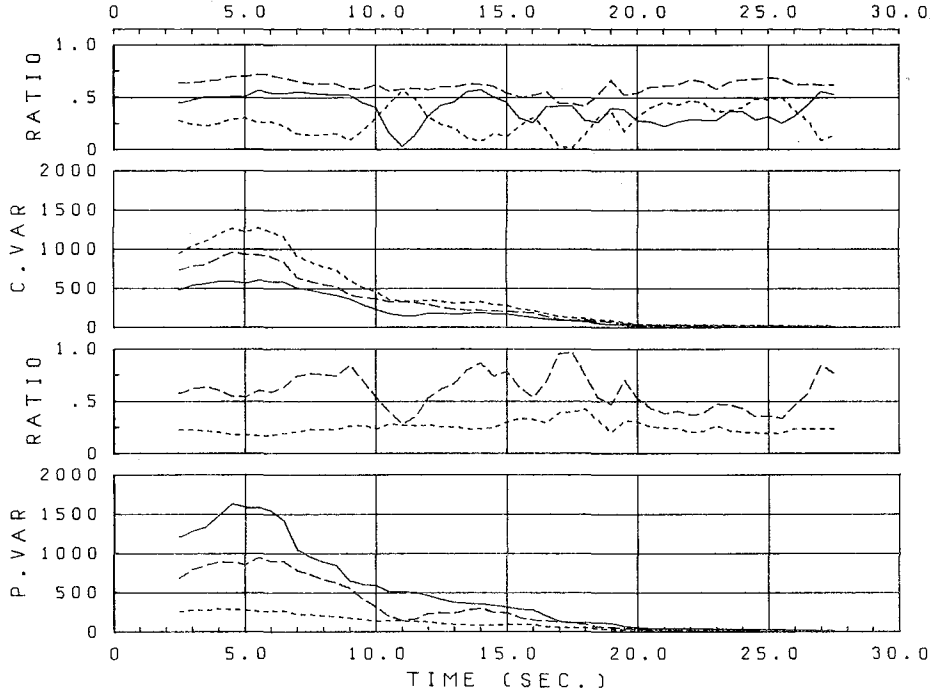
3345 WILSHIRE BOULEVARD, BASEMENT, LOS ANGELES, CAL.



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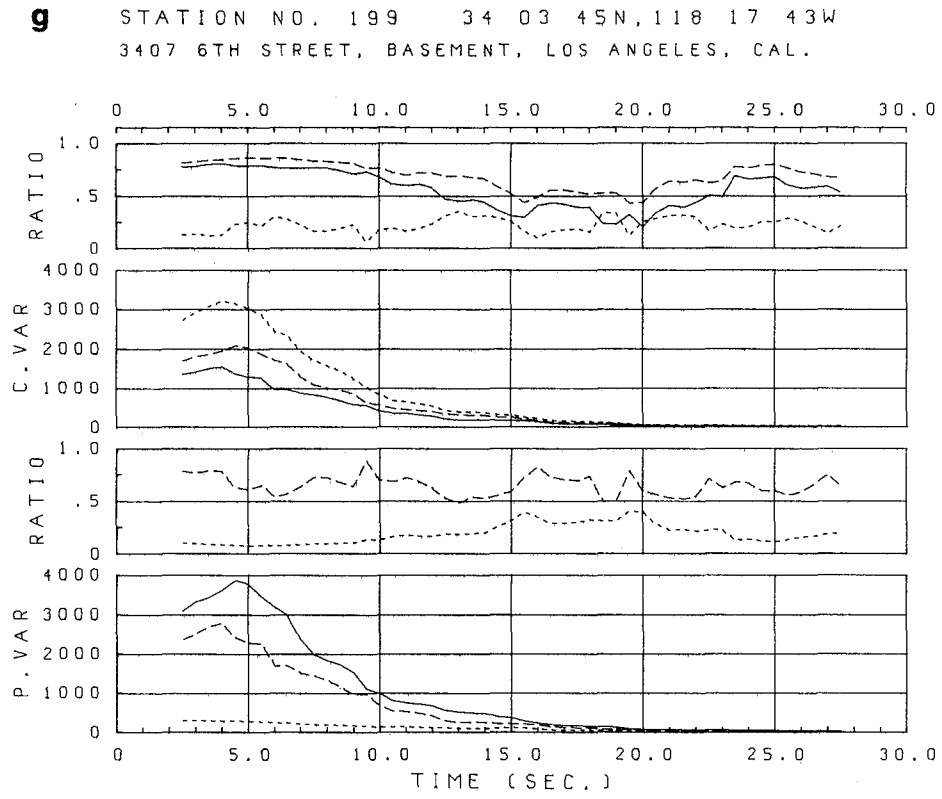


Fig. 3.17 (continued)

IV. FREQUENCY CONTENT OF GROUND MOTIONS ALONG PRINCIPAL AXES

A. GENERAL

The variation of frequency content with time has been examined previously using the concept of an evolutionary spectrum [33,34,28] and the concept of a response envelope spectrum [45]. While the use of these concepts is desirable, they cannot be applied to the moving-window technique adopted in this study. Applying the moving-window technique, Fourier amplitude spectra are obtained for the principal components of motion of duration ΔT centered on time t_o.

The concept of power and power spectrum will be reviewed briefly [9]. Let $a_i(t)$ and $A_i(\omega)$ represent a real time function and its corresponding Fourier frequency function, respectively. In this discussion, $a_i(t)$ represents acceleration of motion and power will be regarded as the square of the magnitude of process $a_i(t)$, even though it does not have units of energy per unit of time. Thus, the square of $a_i(t)$ at time t_o, i.e.

$$|a_i(t_o)|^2 \tag{4.1}$$

is termed the instantaneous power at time t_o. Correspondingly, the integral of instantaneous power over the range $-\infty < t < +\infty$, i.e.

$$\int_{-\infty}^{\infty} |a_i(t)|^2 \, dt \tag{4.2}$$

is called total energy of process $a_i(t)$ when the infinite integral has a finite value. In practical applications, this integral always has a finite value since the record length of $a_i(t)$ is limited. Theoretically, this integral converges when the time function is defined only in a

finite length or the time function satisfies the Dirichlet's conditions in a mathematical sense. The average power of time function $a_i(t)$ is obtained through the relation

$$\lim_{T\to\infty} \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} |a_i(t)|^2 \, dt \tag{4.3}$$

Process $a_i(t)$ will have a zero value of average power, if it has a finite value of total energy as given by Eq. (4.2).

Correlation functions are defined through the relation

$$R_{ij}(\tau) = \int_{-\infty}^{\infty} a_i(t) \; a_j \; (t + \tau) \; dt \tag{4.4}$$

for processes of finite total energy and through the relation

$$R_{ij}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} a_i(t) \; a_j \; (t + \tau) \; dt \tag{4.5}$$

for processes of finite average power. For processes of the first type, the total energy of $a_i(t)$ and its corresponding spectrum can be related as follows:

$$\begin{aligned}
\int_{-\infty}^{\infty} |a_i(t)|^2 \, dt &= \int_{-\infty}^{\infty} a_i(t) \; a_i(t) \; dt \\
&= \int_{-\infty}^{\infty} a_i(t) \left[\frac{1}{2\pi} \int_{-\infty}^{\infty} A_i(\omega) \; e^{i\omega t} \; d\omega \right] dt \\
&= \frac{1}{2\pi} \int_{-\infty}^{\infty} A_i(\omega) \; d\omega \int_{-\infty}^{\infty} a_i(t) \; e^{i\omega t} \; dt \\
&= \frac{1}{2\pi} \int_{-\infty}^{\infty} A_i(\omega) \; A_i(-\omega) \; d\omega
\end{aligned} \tag{4.6}$$

When function $a_i(t)$ is a real process,

$$A_i(-\omega) = A_i^*(\omega) \tag{4.7}$$

where * denotes the conjugate property. Substituting Eq. (4.7) into Eq. (4.6), Eq. (4.6) becomes

$$\begin{aligned}\int_{-\infty}^{\infty} |a_i(t)|^2 \, dt &= \frac{1}{2\pi} \int_{-\infty}^{\infty} A_i(\omega) \, A_i^*(\omega) \, d\omega \\ &= \frac{1}{2\pi} \int_{-\infty}^{\infty} |A_i(\omega)|^2 \, d\omega \end{aligned} \tag{4.8}$$

The left hand side of Eq. (4.8) represents the total energy of process $a_i(t)$ and the quantity $|A_i(\omega)|^2$ on the right hand side represents energy density associated with a frequency ω which will be called energy spectral density. This relationship is usually referred to as Parceval's theorem. For processes of finite average power, the relation in Eq. (4.8) is slightly changed. Manipulating Eq. (4.5), one finally obtains the relation

$$\begin{aligned} R_{ii}(0) &= \lim_{T\to\infty} \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} a_i(t) \, a_i(t) \, dt \\ &= \lim_{T\to\infty} \frac{1}{2\pi T} \left[\int_{-\infty}^{-\frac{2\pi}{T}} |A_i(\omega)|^2 \, d\omega + \int_{\frac{2\pi}{T}}^{\infty} |A_i(\omega)|^2 \, d\omega \right] \end{aligned} \tag{4.9}$$

The quantity $|A_i(\omega)|^2/T$ in Eq. (4.9) represents average power of the process per unit frequency and will be called power spectral density.

B. NORMALIZED FOURIER AMPLITUDE SPECTRUM WITH MOVING-WINDOW TECHNIQUE

Suppose $a_x(t)$, $a_y(t)$ and $a_z(t)$ represent respectively the ground accelerations along the x, y and z axes. The moving-window

Fourier amplitude spectrum using a window length ΔT centered at time t_o is defined by

$$A_i(\omega, t_o, \Delta T) = \left| f_i(\omega, t_o, \Delta T) \right| \tag{4.10}$$

$$f_i(\omega, t_o, \Delta T) = \int_{t_o - \frac{\Delta T}{2}}^{t_o + \frac{\Delta T}{2}} a_i(t)\, e^{-i\omega t}\, dt \tag{4.11}$$

$$i = x,y,z$$

Using a similar procedure, a set of moving-window Fourier amplitude spectra along principal axes, 1, 2 and 3, is given by

$$A_i(\omega, t_o, \Delta T) = \left| f_i(\omega, t_o, \Delta T) \right| \tag{4.12}$$

$$i = 1,2,3$$

$$\underline{F}(\omega, t_o, \Delta T) = \int_{t_o - \frac{\Delta T}{2}}^{t_o + \frac{\Delta T}{2}} \underline{P}(t_o)\, \underline{a}(t)\, e^{-i\omega t}\, dt \tag{4.13}$$

where

$$\underline{F}(\omega, t_o, \Delta T) = \begin{Bmatrix} f_1(\omega, t_o, \Delta T) \\ f_2(\omega, t_o, \Delta T) \\ f_3(\omega, t_o, \Delta T) \end{Bmatrix} \tag{4.14}$$

$$\underline{a}(t) = \begin{Bmatrix} a_x(t) \\ a_y(t) \\ a_z(t) \end{Bmatrix} \tag{4.15}$$

and $\underline{P}(t_o)$ denotes the principal transformation matrix at time t_o. In this investigation, a constant window length of five seconds was used.

Therefore, ΔT can be dropped out of the subsequent equations for simplicity.

Since the Fourier amplitude spectrum usually oscillates rapidly, some technique is required to make it smooth. Here, it is made smooth through convolution weights 1/4, 1/2 and 1/4, i.e. the smoothed Fourier amplitude spectrum is obtained through the relation

$$A(\omega, t_o) = \frac{1}{4} A(\omega - \Delta\omega, t_o) + \frac{1}{2} A(\omega, t_o) + \frac{1}{4} A(\omega + \Delta\omega, t_o) \qquad (4.16)$$

The purpose of the moving-window Fourier amplitude analysis is to examine the general characteristics of the frequency content with time. Therefore, the Fourier amplitude spectrum has been made much smoother by using the filter of convolution weights more than once.

Since intensity of ground motion can be expressed in terms of variances as previously shown, the moving-window Fourier amplitude spectrum can be normalized with respect to its maximum value generated for time t_o. In this report, the normalized moving-window Fourier amplitude spectrum is assigned levels of 0 through 5 by the relation

$$\bar{A}_i(\omega, t_o) = \frac{5X\ A_i(\omega, t_o)}{A_i'(t_o)} \qquad (4.17)$$

$$i = 1,2,3$$

where $\bar{A}_i(\omega, t_o)$ $(i = 1,2,3)$ represents a so-called normalized moving-window Fourier amplitude spectrum and $A_i'(t_o)$ is the maximum amplitude generated at time t_o, i.e.

$$A_i'(t_o) = \text{Max}\ [A_i(\omega_o, t_o), A_i(\omega_1, t_o), A_i(\omega_2, t_o), \ldots.] \qquad (4.18)$$

$$i = 1,2,3$$

C. RESULTS AT STATION NO. 264

Moving-window Fourier amplitude analysis has been carried out for the 29 stations previously selected in area groups A through F. The Fourier transformations have employed the Fast Fourier Transform technique using 256 samples of each function. Since the time intervals of digitized data were taken as 0.02 seconds, a time window length of 5 seconds was selected which is identically the same as that used in the time domain formulation of principal axes.

Spectral amplitudes were evaluated for discrete values of frequency up to 8 Hz, were smoothed by weighed convolutions and were normalized using the maximum value obtained over the entire frequency range. In Figs. 4.1, the time dependencies of frequency content are shown using three dimensional spectral diagrams in which the x and y axes denote time and frequency, respectively, and the contour lines represent levels of the normalized Fourier amplitude spectra. Each line denotes a level of 1, 2, 3 and 4, which describes the magnitude of spectral amplitude with respect to the maximum magnitude which is assigned a value of 5. These figures show the time dependent frequency content along the principal axes of the accelerogram recorded at station No. 264. Figures 4.1a, b, c and d present the results obtained by repeating the smoothing procedure zero, ten, twenty and forty times, respectively.

The shaded zones in these diagrams are areas where the normalized Fourier amplitude takes on values greater than four, i.e. they represent zones in which the Fourier amplitudes are near peak values. In this investigation, the main purpose is to characterize the general features of the time dependency of frequency content. For this

purpose, the procedure using twenty times filtering was adopted for other stations.

D. RESULTS OF MOVING-WINDOW FOURIER AMPLITUDE SPECTRUM ANALYSIS

For those stations included in area groups A through F, the Fourier amplitude spectrum analysis using the moving-window concept has been carried out. The three dimensional diagrams in Figs. 4.2 and 4.3 and similar diagrams in Appendices A and E represent the time dependencies of frequency content for ground motions along principal axes. The results for stations in area groups A and B are shown in Figs. 4.2 and 4.3, respectively, and the results for stations in area groups C-E and F are shown in Appendices E and A, respectively. As described previously, the shaded zones in those figures represent the highest range of spectral magnitude; thus, indicating the corresponding range of dominant frequencies at time t_o.

E. OBSERVATION OF RESULTS

It is commonly recognized that power spectral density is a most significant characteristic used in simulating a ground motion process. Whereas for a nonstationary process most basic statistical properties cannot be evaluated theoretically, it is often practical to apply procedures to this process which are similar to those used for a stationary process and to treat its properties in a statistical manner.

Using Parceval's theorem, one can estimate the power spectral density of the process at time t_o and the variation of the spectral density with time by taking the square values of amplitude of the time dependent Fourier spectrum. As these Fourier spectrum diagrams have been normalized and made smooth by passing a filter weighing 1/4, 1/2

and 1/4 convolutions, one can obtain the general time dependency of dominant frequencies and the general shape of the spectral density function of the ground motion process. The characteristic features of these diagrams can be summarized as follows:

(1) In several cases, though the results have been smoothed, the diagrams show unexplainable complexities which may be caused by the complex nature of the ground motions as influenced by energy release mechanism, wave propagation path, local geology and consequent wave dispersion including possible soil-structure interaction effect.

(2) The dominant frequency is found to have discreasing values with time. This property coincides with the results reported by Saragoni and Hart [38] which were obtained by separating the accelerogram into several segments and determining the power spectral density function for each segment.

(3) In some cases, the dominant frequency changes its value suddenly at a fixed time which may indicate the arrival of different types of seismic waves.

(4) Spectral density at time t_o, which can be evaluated by a cross sectional view of the three dimensional diagram, becomes higher and more sharply peaked as the frequency parameter increases towards the dominant frequency. It then gradually decreases with increasing values of the frequency parameter beyond the dominant frequency. This tendency can be observed most clearly for the accelerograms which were recorded on soft ground.

(5) Generally, it is observed that the spectral density functions derived from the three dimensional diagrams are less sharply peaked for motions along the minor axis than for motions along the major and intermediate axes. This tendency agrees with the results of the moving-window analysis in the frequency domain which show that principal variances along the minor axis are more uniform than those along the major and intermediate axes.

(6) The frequency content for motions along the major and intermediate axes, both of which are nearly horizontal, is similar to each other. In some cases, however, the frequency content for motion along the intermediate principal axis is more uniform than for motion along the major principal axis.

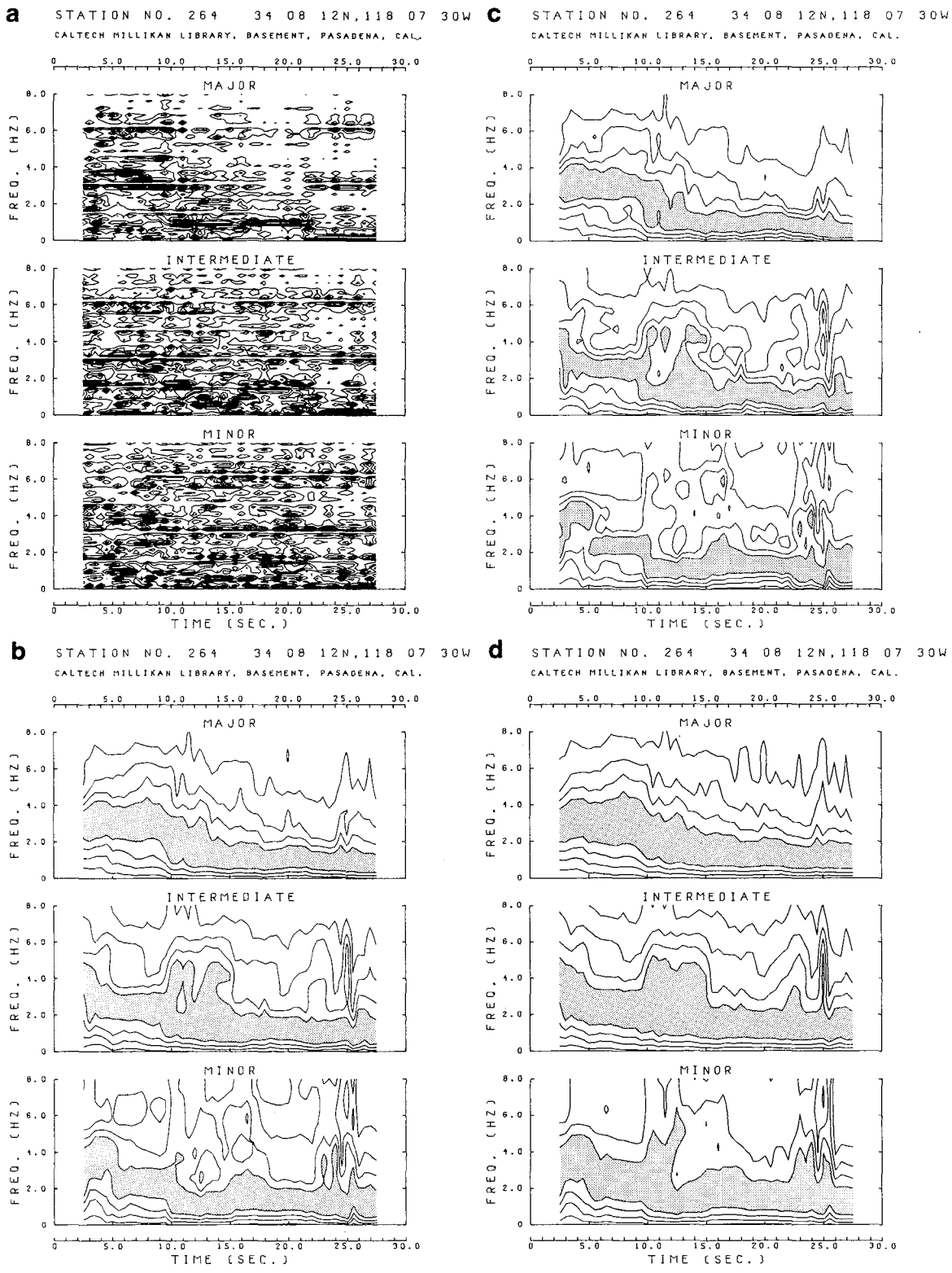


Fig. 4.1 Time dependent frequency distribution at station No. 264.

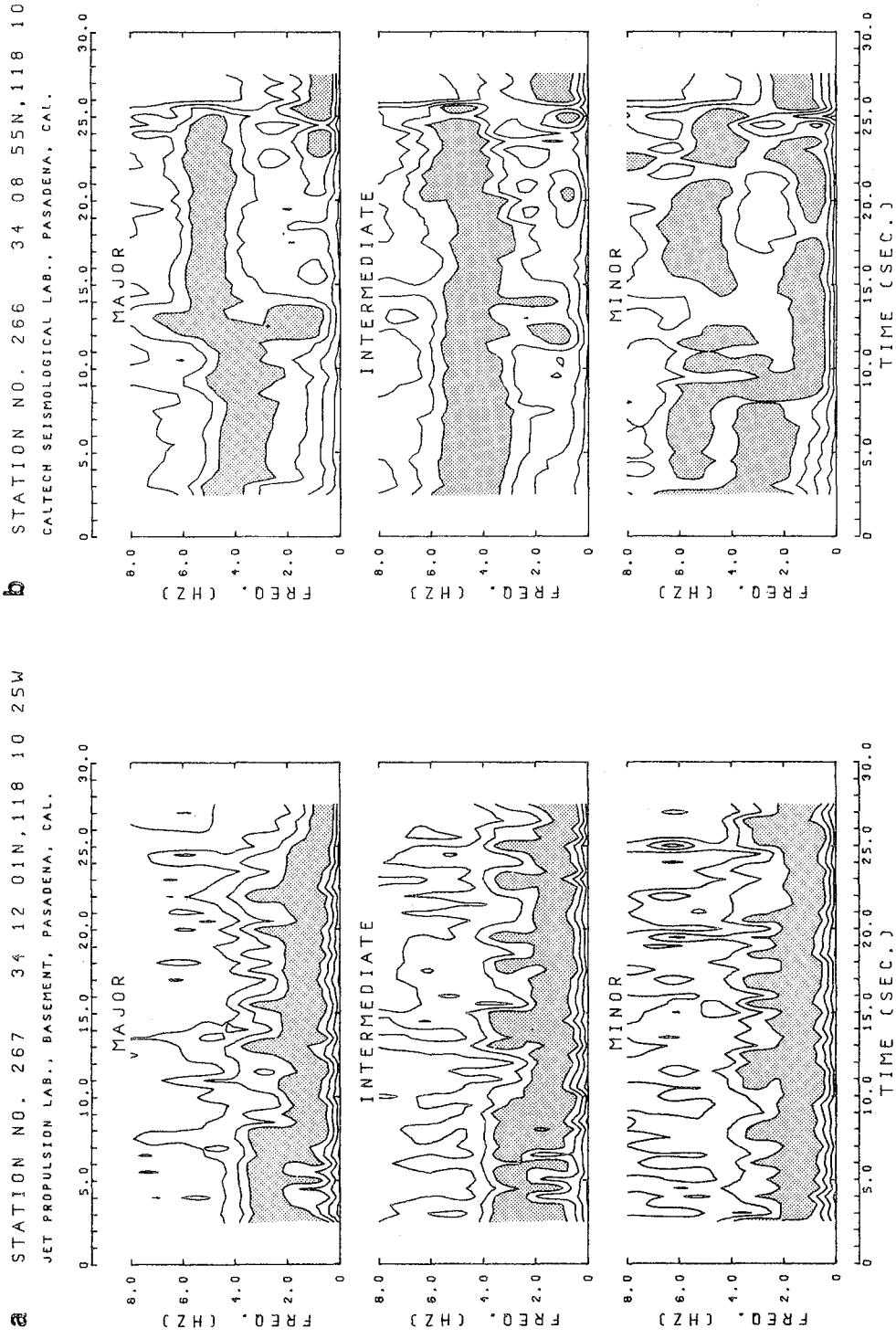


Fig. 4.2 Time dependent frequency distribution in area A.

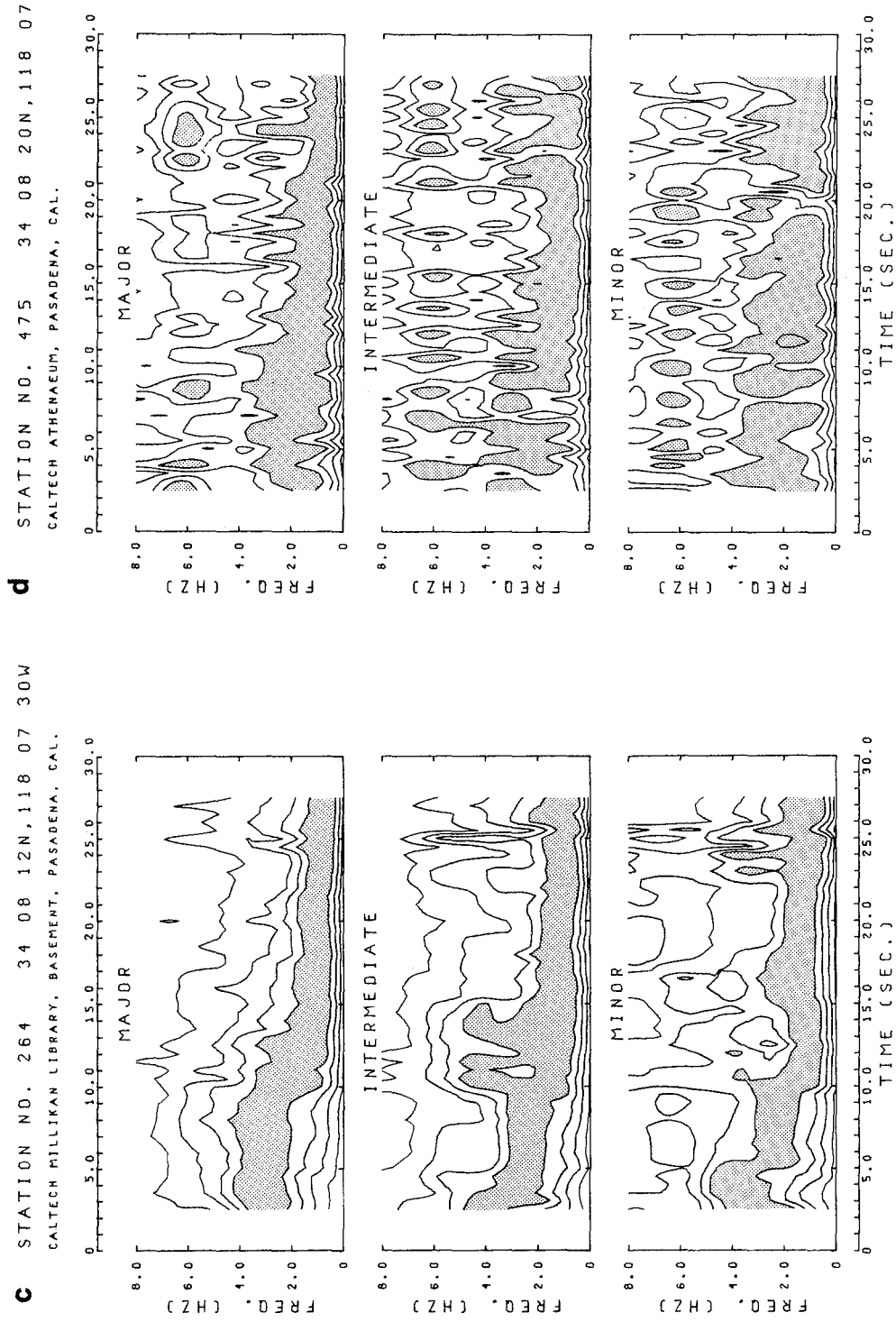


Fig. 4.2 (continued)

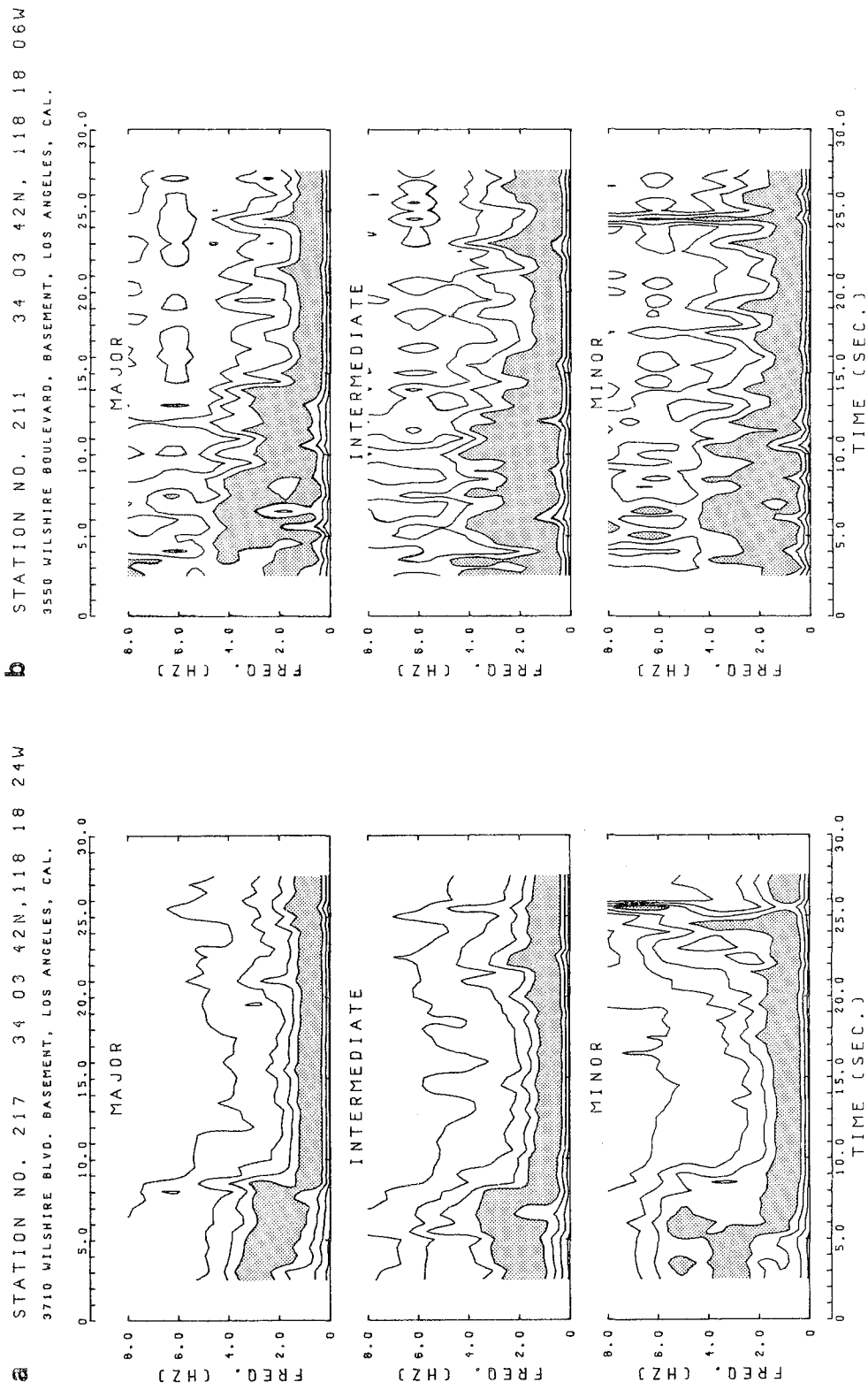


Fig. 4.3 Time dependent frequency distribution in area B.

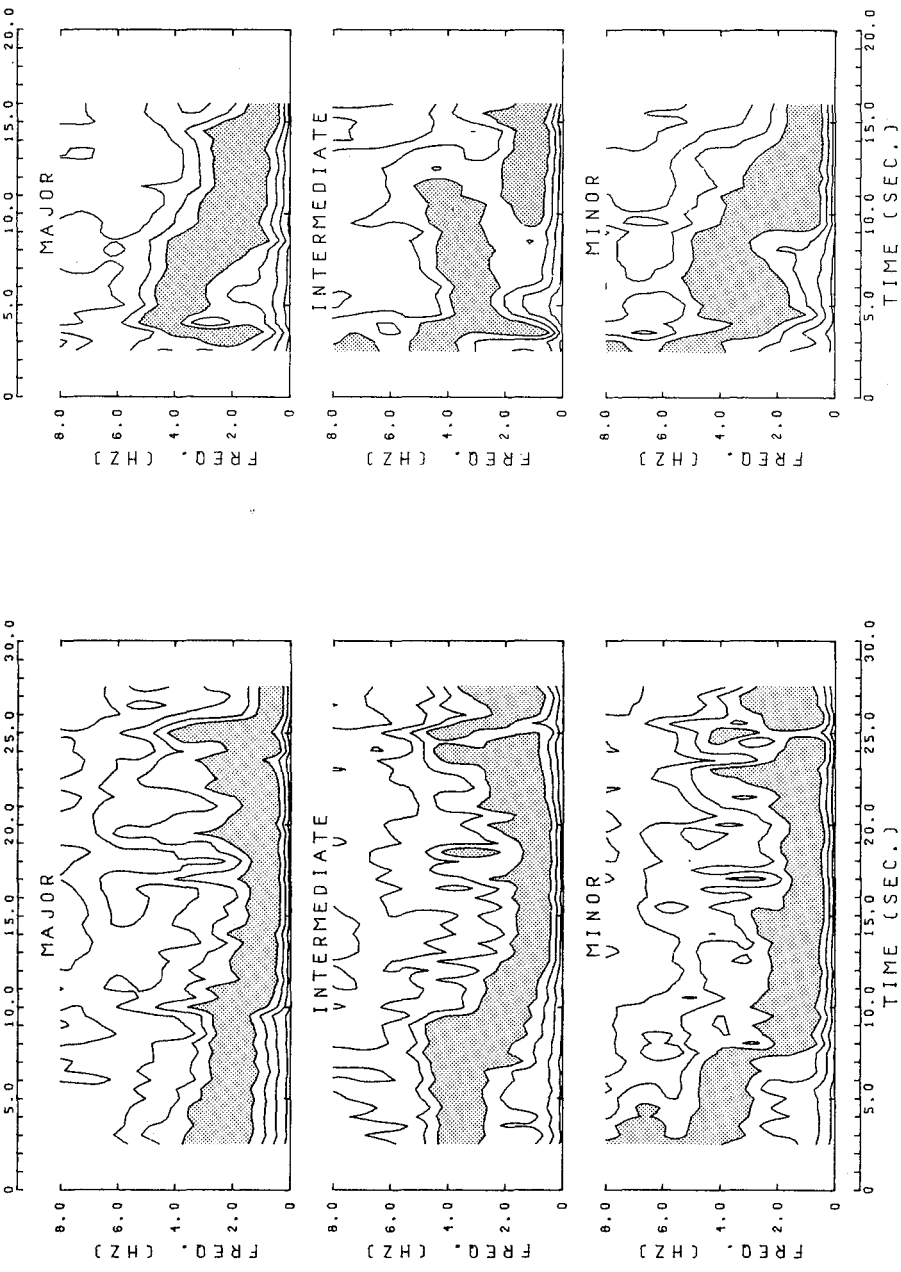


Fig. 4.3 (continued)

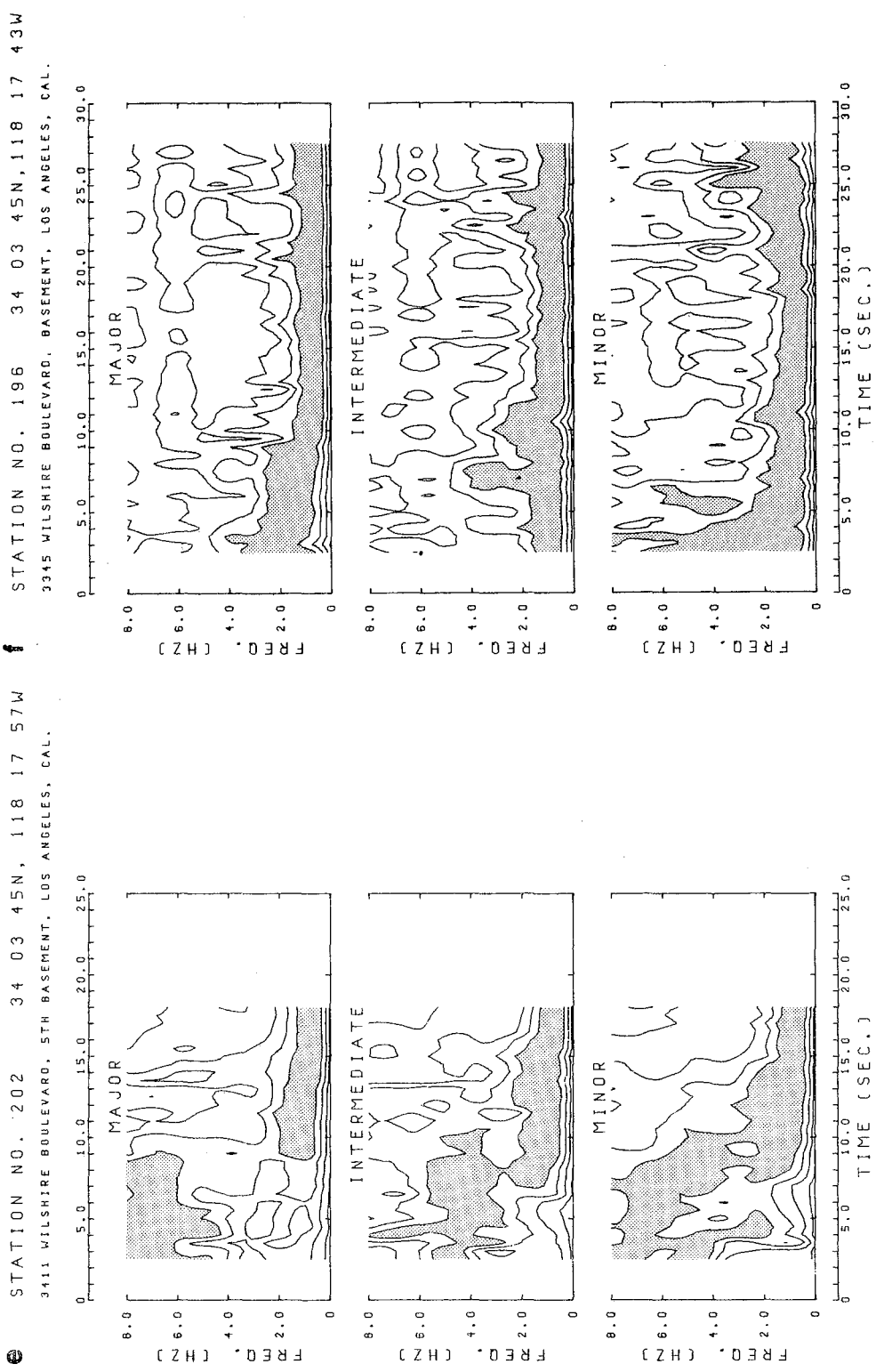


Fig. 4.3 (continued)

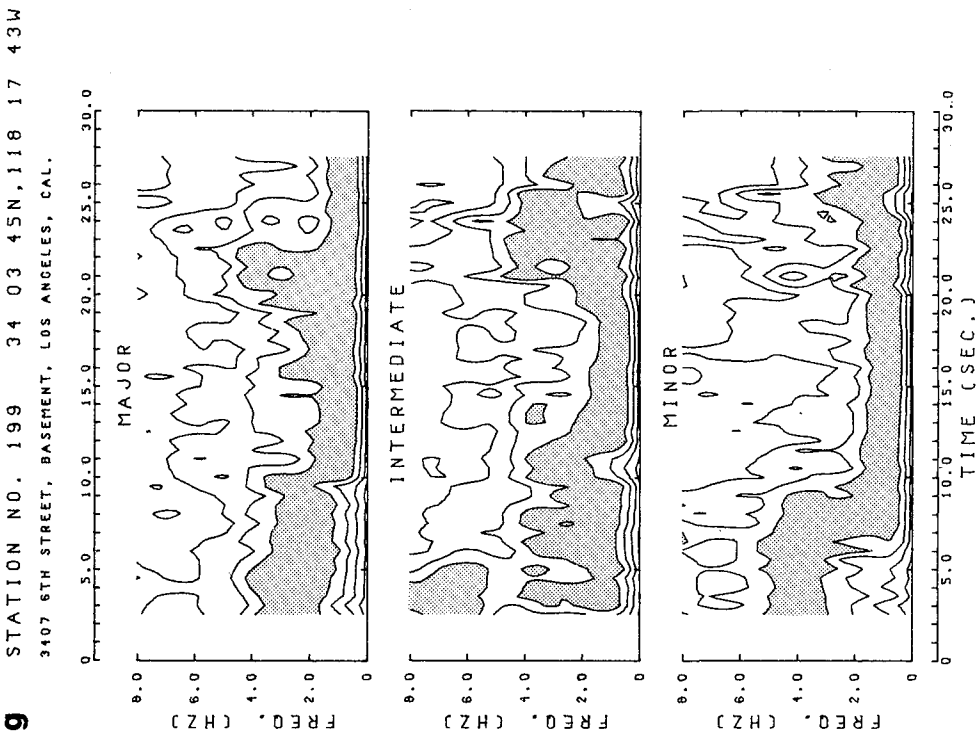


Fig. 4.3 (continued)

V. GENERATION OF THREE COMPONENTS OF GROUND MOTION

A. GENERAL

It is concluded in the previous sections that the three translational components of ground motion are independent of one another in a statistical sense, provided they are directed along a set of principal axes. Therefore, one can simulate three components of ground motion by generating them, of which intensity and frequency content are given appropriately, independently along their corresponding principal axes. One can, if necessary, obtain the three components of ground motion along a set of principal axes of the structural system for use in dynamic analysis by transforming them in accordance with horizontal and vertical rotational angles which may have been determined from the relationship between the location of the structural system and the possible location of an earthquake.

In the first part of this chapter, the methodology to generate a one-dimensional nonstationary random process in both intensity and frequency content is introduced. Four sample processes are produced by employing this method. In the second part, this methodology is applied to the simulation of three components of motion along principal axes, each of which is provided with appropriate intensity and frequency content. Based upon an assumption of relationship between the location of the structural system and that of the epicenter, these three components along a set of principal axes are transformed and three components along a set of structural principal axes are produced. Finally, assuming as if these three components were recorded by an accelerograph of which axes coincide with structural principal axes, directions of principal axes of ground motion, principal variances of ground motion

and frequency content of principal motion are evaluated through the routine procedures which have been employed in the previous chapters to analyze the ground motions produced by the San Fernando earthquake.

B. SIMULATION OF A NONSTATIONARY PROCESS

1. Generation of a Random Process Having an Arbitrary Power Spectral Density.

The common procedures to simulate a nonstationary random process which has an appropriate spectral density are roughly classified as shown in Table 5.1 [30]. The method employed in this investigation belongs to the (III)rd group, which has been proposed by Toki [44,16]. The method is to generate a random process having an arbitrary spectral density by superposing a sufficient number of sinusoidal waves. The technique is explained briefly in the following. Let a ground motion process $a(t)$ be represented through the relation

$$a(t) = \sqrt{\frac{2}{N}} \sum_{n=1}^{N} \cos (\eta_n t + \phi_n) \tag{5.1}$$

in which η_n and ϕ_n are probabilistic variables which denote the circular frequency and the phase angle of the sinusoidal wave, respectively. Suppose that the probabilistic distribution of η_n is expressed by probability density function $p(\eta)$ and that the variable ϕ_n is distributed uniformly over the range $0 \leq \phi < 2\pi$. The auto-correlation function of process $a(t)$ is given by

$$\begin{aligned} R_a(\tau) &= E\,[a(t)\ a(t+\tau)] \\ &= \frac{1}{2}\ E\,[\cos \eta\ \tau + \cos \{\eta(2t+\tau) + 2\phi\}] \end{aligned} \tag{5.2}$$

Since the phase angle ϕ is assumed to be distributed uniformly, the second part of the expected value in the right hand side of Eq. (5.2)

equals zero and Eq. (5.2) becomes

$$R_a(\tau) = \frac{1}{2} E[\cos \eta \tau]$$

$$= \frac{1}{2} \int_{-\infty}^{\infty} \cos \eta \tau \cdot p(\eta) \, d\eta \qquad (5.3)$$

The probability density function $p(\eta)$ is symmetrical with respect to $\eta = 0$, therefore, Eq. (5.3) is written in the range $\eta > 0$ through

$$R_a(\tau) = \int_{0}^{\infty} \cos \eta \tau \cdot p(\eta) \, d\eta \qquad (5.4)$$

Let the power spectral density of process $a(t)$ be designated by $S(\omega)$. As the power spectral density function is expressed as a Fourier pair of the corresponding auto-correlation function, the power spectral density function is given through the relation

$$S(\omega) = \int_{-\infty}^{\infty} R_a(\tau) \, e^{-i\omega\tau} \, d\tau$$

$$= \int_{0}^{\infty} p(\eta) \, d\eta \int_{-\infty}^{\infty} \cos \eta \tau \, e^{-i\omega\tau} \, d\tau$$

$$= \pi \int_{0}^{\infty} p(\eta) \, \{\delta(\omega-\eta) + \delta(\omega+\eta)\} \, d\eta$$

$$= \pi \, p(\omega) \qquad (5.5)$$

in which δ denotes a Dirac's δ function. Equation (5.5) indicates that the power spectral density of the process is similar to the probability distribution function of the circular frequency of sinusoidal waves by π. An average power of one sinusoidal wave is expressed through

$$\frac{1}{T}\int_0^T \cos^2(\eta t+\phi)\,dt = \frac{1}{T}\left[\frac{t}{2} + \frac{\sin 2(\eta t+\phi)}{4\eta}\right]_0^T \qquad (5.6)$$

Since phase angle ϕ is assumed to be uniformly distributed, an average power is expected to be 1/2. Therefore, if N sinusoidal waves are superposed, the expected average power will be equal to $N/2$.

Using Toki's method, one can simulate a ground motion process which has an arbitrary power spectral density giving an appropriate probability distribution to the variable circular frequency η.

2. Generation of a Random Process Having Nonstationary Frequency Content

To simulate a strong ground motion process as a nonstationary random function in frequency content has been studied by a few, such as by Bogdonaff et al. [7] or Hart et al. [38,18]. The former method is to superpose sinusoidal waves having their own deterministic intensity functions individually. The later one is to devide the process into several separate segments and to generate a stationary process within each segment having an appropriate power spectral density independently.

The method employed in this investigation to generate a non-stationary random process is to divide a process into segments in a continuous manner and superpose sinusoidal waves of which spectral density function will coincide with the prescribed time dependent spectral density function. The procedures are as follows:

(i) Let G denote the time dependent spectral density of motion which is defined in the range $0 \leq t < T$, where T designates the duration of motion.

(ii) Generate a random number t_o which is uniformly distributed between o and T. Then one can obtain the spectral density $G = G(\omega,t_o)$ at time t_o.

(iii) Applying Toki's method, within a small segment of ΔT being centered at t_o, generate a sinusoidal wave of which circular frequency is η whose probability distribution is similar to that of spectral density function $G(\omega,t_o)$, and of which phase angle is distributed uniformly over the range $0 \leq \phi < 2\pi$. One cannot always find an appropriate sinusoidal wave at this step. If not, one should return to step (ii) and then continue on.

(iv) To satisfy the continuous boundary at the ends of the segment, the sinusoidal wave is passed through a filter which has the property

$$H(t) = 0 \quad \begin{cases} t < t_o - \frac{\Delta T}{2} \\ t > t_o + \frac{\Delta T}{2} \end{cases} \qquad (5.7)$$

$$\lim_{t \to t_o + \frac{\Delta T}{2}} H(t) = 0$$

In this report, a cosine bell function

$$H(t) = 0 \quad \begin{cases} t < 0 \\ t \geq \Delta T \end{cases} \qquad (5.8)$$

$$H(t) = \frac{1}{2}\left(1 - \cos\frac{2\pi t}{\Delta T}\right) \quad 0 \leq t < \Delta T$$

is adopted for the filtering procedure.

(v) Repeat the procedures from (ii) through (iv) and simulate a nonstationary random function of duration T by superposing a certain number of sinusoidal waves of short duration ΔT.

(vi) Finally multiply the process by a deterministic intensity function which gives an appropriate nonstationarity to the intensity of motion.

It should be noticed that the variance of the process, which is given by

$$E\,[a(t_o)\;a(t_o)] \;=\; \int_{-\infty}^{\infty} G\,(\omega,t_o)\;d\omega \qquad (5.9)$$

will be dependent upon time t_o, depending upon the shape of the time dependent power spectral density function. If the variances of the process vary with time t_o, one cannot produce random process $a(t)$ with an appropriate deterministic intensity by multiplying it with intensity function $\zeta(t)$.

Identical to the case of recorded strong ground motion, the integrated velocity and double integrated displacement of the simulated motion often have unreasonable diverging values with time. The baseline correction of the simulated accelerograms are performed by fitting a parabolic curve to the velocity history by a least square method [6]. As previously reported [23], due to the parabolic curve correction, an offset of the accelerogram is introduced at the ends of motion. Therefore, a small linear correction is carried out at the beginning of the accelerogram which will make it possible for the acceleration to start from zero. This correction might cause the integrated velocity or double integrated displacement curves to be altered but it makes negligible changes in the acceleration curve.

C. EXAMPLES IN ONE-DIMENSIONAL FORM

1. Review of Past Simulated Motions

Spectral density function $G(\omega)$ and deterministic intensity function $\zeta(t)$ are commonly recognized to be the most significant characteristics for simulating a ground motion process. One can find many types of spectral density and deterministic intensity functions proposed previously. Most of them have been derived by analyzing actual records and introducing empirical relations such as

$$G(\omega) = \frac{1 + 4 h_g^2 \frac{\omega^2}{\nu_g^2}}{\left(1 - \frac{\omega^2}{\nu_g^2}\right)^2 + 4 h_g^2 \frac{\omega^2}{\nu_g^2}} B \qquad (5.10)\ [43]$$

$$G(\omega) = \frac{1}{2} \frac{\alpha K}{(\omega-\theta)^2 + \alpha^2} + \frac{1}{2} \frac{\alpha K}{(\omega+\theta)^2 + \alpha^2} \qquad (5.11)\ [8]$$

$$G(\omega) = 2 B_o \alpha \frac{\omega^2 + (\alpha^2+\theta^2)}{\omega^4 + 2(\alpha^2-\theta^2)\omega^2 + (\alpha^2+\theta^2)^2} \qquad (5.12)\ [4]$$

$$G(\omega) = A_1 e^{-b^2\omega^2} + A_2 \omega^2 e^{-4b^2\omega^2} \qquad (5.13)\ [22]$$

$$G(\omega) = \frac{2 \omega^2 e^{-\frac{2\omega}{\omega_p}}}{\pi \omega_p^3} \qquad (5.14)\ [44]$$

to serve as the spectral density function for simulated motions [30]. Similarly, many investigators have established the shapes of intensity functions which give deterministic nonstationarity to the process. The functions

$$\zeta_{(t)} = \begin{cases} 0 & t \leq 0 \\ ae^{-ct} & t > 0 \end{cases} \qquad (5.15)\ [8]$$

$$\zeta_{(t)} = \begin{cases} 0 & t \leq 0 \\ ate^{-ct} & t > 0 \end{cases} \qquad (5.16)\ [7]$$

$$\zeta_{(t)} = \begin{cases} 0 & t \leq 0 \\ e^{-\alpha t} - e^{-\beta t} & t > 0 \end{cases} \qquad (5.17)\ [41]$$

$$\zeta_{(t)} = \begin{cases} 0 & t \leq 0 \\ a \frac{t}{t_p} e^{1-t/t_p} & t > 0 \end{cases} \qquad (5.18)\ [44]$$

$$\zeta_{(t)} = \begin{cases} I_o \left(\frac{t}{t_1}\right)^2 & 0 \leq t < t_1 \\ I_o & t_1 \leq t < t_2 \\ I_o e^{-c(t-t_2)} & t_2 \leq t \end{cases} \qquad (5.19)\ [1]$$

$$\zeta_{(t)} = \begin{cases} (a_1 + a_2 t) e^{-ct} \\ (a_1 + a_2 t) e^{-ct^2} \end{cases} \qquad (5.20)\ [22]$$

and those by Jennings, et al. [23] have been employed for this purpose.

2. Characteristics of Simulated Motions

Four samples are produced which have nonstationary properties in both frequency content and intensity. For a spectral density function, the type which has been proposed by Kanai and Tajimi [43] is employed,

$$G = G(\omega,t) = \frac{1 + 4 h_g^2 \frac{\omega^2}{\nu_g^2}}{\left(1 - \frac{\omega^2}{\nu_g^2}\right)^2 + 4 h_g^2 \frac{\omega^2}{\nu_g^2}} \; B \qquad (5.21)$$

in which ω denotes circular frequency and ν_g and h_g represent the dominant circular frequency and a parameter which indicates sharpness of the peak, respectively. The dominant circular frequency ν_g is assumed to be dependent upon time, having the form

$$\nu_g = \nu_g(t)$$

$$= \frac{a}{bt^c + 1} \tag{5.22}$$

Coefficients a, b and c in Eq. (5.22) are fixed as 5.027×10^{1}, 1.550×10^{-2} and 2.041, respectively, in which case the dominant circular frequencies at time t = 0, 6 and 20 second become

$$\nu_g(0) = 2\pi \cdot 8$$

$$\nu_g(6) = 2\pi \cdot 5$$

$$\nu_g(20) = 2\pi \cdot 1$$

showing a rapid change in the dominant frequency with time. The parameter h_g is fixed at 0.3 over the entire duration of motion.

For a deterministic intensity function, the shape

$$\zeta_{(t)} = (a_1 + a_2\, t)\, e^{-ct} \tag{5.23}$$

proposed by Iyengar [22] is applied. Coefficients a_1, a_2 and c are determined as 0, 4.53×10^{-1} and 1/6, in which case the resulting maximum intensity of $\zeta(6)$ becomes unity and ratios $\zeta(12)/\zeta(6)$ and $\zeta(20)/\zeta(6)$ become 0.74 and 0.32, respectively.

As derived from Eq. (5.9), the variances of the process are given through

$$E[a(t_o)\ a(t_o)] = \int_{-\infty}^{\infty} G(\omega,t_o)\ d\omega$$

$$= \int_{-\infty}^{\infty} \frac{1 + 4\ h_g^2\ \frac{\omega^2}{\nu_g^2}}{\left(1 - \frac{\omega^2}{\nu_g^2}\right)^2 + 4\ h_g^2\ \frac{\omega^2}{\nu_g^2}}\ B\ d\omega$$

$$= \nu_g(t_o) \int_{-\infty}^{\infty} \frac{1 + 4\ h_g^2\ \nu^2}{(1-\nu^2)^2 + 4\ h_g^2\ \nu^2}\ B\ d\nu$$

$$= \nu_g(t_o) \cdot C \cdot B \qquad (5.24)$$

where ν is equal to ω/ν_g and C given by the integral can be expressed as $C = C\ (h_g)$. To give an appropriate deterministic intensity by the shape function, the variances of the process should be distributed uniformly, i.e. the integral of power spectral density function should have identical values at every time t_o. The parameter h_g in this investigation is assumed to be constant over the entire duration of motion. Therefore, to yield uniform variances to the process, the quantity B should be given by

$$B = B(t_o)$$

$$= \frac{\bar{B}}{\nu_g(t_o)} \qquad (5.25)$$

in which quantity $\bar{B}$ is constant either with circular frequency ω or with time t_o. Having obtained the process of uniform variances and of nonstationarity in frequency content using the spectral density function

$$G(\omega,t) = \frac{1 + 4\, h_g^2 \frac{\omega^2}{\nu_g^2}}{\left(1 - \frac{\omega^2}{\nu_g^2}\right)^2 + 4\, h_g^2 \frac{\omega^2}{\nu_g^2}} \quad \frac{\bar{B}}{\nu_g}$$

$$\nu_g = \nu_g(t) \tag{5.26}$$

, the process is multiplied by the deterministic intensity function given by Eq. (5.23) and the zero baseline is determined by a parabolic curve to give reasonable velocity and displacement time histories. Figures 5.1a and 5.1b show the prescribed properties of the deterministic intensity function and the spectral density function, respectively. It might be noticed that the deterministic function is plotted in term of

$$\zeta'(t) = \frac{1}{\sqrt{2}}\, \zeta(t) \tag{5.27}$$

and the spectral density is expressed in terms of the Fourier amplitude.

3. Presentation of Examples

Based upon the prescribed power spectral density and deterministic intensity, four samples are produced. The time histories and their spectral diagrams obtained by a Fourier amplitude spectral analysis with a moving-window technique are presented in Figs. 5.2 through 5.5. These spectral diagrams are evaluated by passing the filter of convolution weights and smoothed. The shaded zones represent the dominant frequency with time t_o, which were obtained in identically the same manner described in the previous chapter.

4. Observation of Results

For illustration, the time dependent characteristics of the dominant frequency is assumed to vary with time in a rapid manner in

these examples. The sample random processes seem to be obtained with much success. The general tendency of the time dependency of frequency content coincides well with that of the prescribed spectral density and the intensity agrees well with the prescribed deterministic shape function.

The method introduced in this investigation cannot always be applied to the simulation of a random process having an arbitrary non-stationarity in both frequency content and deterministic intensity. The difficulty lies in determining a form of time dependent spectral density function which has an arbitrary form at any time but retains identical variances, i.e. the same quantity of power over the entire duration of motion. For example, if in Eq. (5.21) both parameters h_g and ν_g were assumed to change with time, the evaluation of quantity B to give uniform variances over the entire duration of motion might become difficult. It is concluded, however, that if a spectral density function having a shape which varies with time but having power independent of time can be found, the random process having nonstationarity in both frequency content and deterministic intensity can be simulated.

D. EXAMPLES IN THREE-DIMENSIONAL FORM

1. Characteristics of Simulated Motions

Previously general characteristics of motion along a set of principal axes are evaluated by analyzing recorded motions produced by the San Fernando earthquake and a method to generate a nonstationary process both in frequency content and intensity is introduced. As the principal axes of motion are defined along which the components of motion are statistically independent of one another, the methodology used to simulate a one-dimensional nonstationary process can be extended

to the simulation of three components of motion. If desired, one can easily obtain components of motion along structural principal axes for use in dynamic analysis by multiplying the principal components by a transformation matrix which defines coordinate rotation between the principal axes of motion and the principal axes of the structural system.

The shapes of spectral density function along principal axes are specified to take similar forms given by

$$ {}_iG(\omega,t) = \frac{1 + 4\,{}_ih_g^2\,\frac{\omega^2}{{}_i\nu_g^2}}{\left(1 - \frac{\omega^2}{{}_i\nu_g^2}\right)^2 + 4\,{}_ih_g\,\frac{\omega^2}{{}_i\nu_g^2}}\;\frac{\bar{B}}{{}_i\nu_g} \qquad (5.28) $$

$$ i = 1.2,3 $$

which is identical to that used in the one-dimensional simulation. In the three-dimensional simulation, the dominant circular frequency which is assumed to be time dependent will take a form changing moderately with time, i.e.

$$ \begin{aligned} {}_i\nu_g &= {}_i\nu_g(t) \\ &= 2\pi\,(at + b) \qquad (5.29) \\ i &= 1,2,3 \end{aligned} $$

where coefficients a and b are equal to -2/25 and 17/5, respectively, and the resulting dominant circular frequencies ${}_i\nu_g(5)$ and ${}_i\nu_g(30)$ (i=1,2,3) equal 6π and 2π, respectively. The parameter ${}_ih_g$ in the power spectral density function is assigned values 0.2, 0.3 and 0.6 for the major, intermediate and minor principal axes, respectively. These values reflect the finding that the minor component of motion consists of a wider frequency range than the intermediate component and that the intermediate component consists of a wider frequency range than the major

component. As the number of sinusoidal waves being superposed is identically the same among the three components, the quantities of average power of these simulated components are specified to be identical. Thus, one can obtain the processes of which variances are distributed uniformly not only over the entire duration of motion but also among the three components. Therefore, appropriate intensities can be given by multiplying principal motions by their corresponding deterministic intensity functions. The deterministic intensities of motion along the major, intermediate and minor principal axes are specified as shown at the bottom of Fig. 5.6 by the solid, intermediate-dashed and short-dashed curves, respectively.

After the components of motion along a set of principal axes have been generated, assuming the principal axes of the structural system to be directed to the North-South, East-West and vertical, the components along a set of structural axes are obtained for use in dynamic analyses by multiplying the principal motions by the transformation matrix as follows:

$$\begin{Bmatrix} a_{NS}(t) \\ a_{EW}(t) \\ a_{UD}(t) \end{Bmatrix} = \underline{T}(t) \begin{Bmatrix} a_1(t) \\ a_2(t) \\ a_3(t) \end{Bmatrix} \tag{5.30}$$

where

$$\underline{T} = \begin{bmatrix} \sin\phi_1 \cos\theta_1 & \sin\phi_2 \cos\theta_2 & \sin\phi_3 \cos\theta_3 \\ \sin\phi_1 \sin\theta_1 & \sin\phi_2 \sin\theta_2 & \sin\phi_3 \sin\theta_3 \\ \cos\phi_1 & \cos\phi_2 & \cos\phi_3 \end{bmatrix} \tag{5.31}$$

in which ϕ_i and θ_i (i = 1,2,3) represent vertical and horizontal directional angles of the corresponding principal axes. The transformation matrix $\underline{T}(t)$ is mathematically a transpose matrix of the principal transformation matrix $\underline{P}(t)$. Though the matrix $\underline{T}$ contains six variables, ϕ_1, θ_1, ϕ_2, θ_2, ϕ_3 and θ_3, they are interdependent through the orthogonal conditions.

$$\begin{aligned} &\sin\phi_1 \sin\phi_2 \cos(\theta_1 - \theta_2) + \cos\phi_1 \cos\phi_2 = 0 \\ &\sin\phi_2 \sin\phi_3 \cos(\theta_2 - \theta_3) + \cos\phi_2 \cos\phi_3 = 0 \\ &\sin\phi_3 \sin\phi_1 \cos(\theta_3 - \theta_1) + \cos\phi_3 \cos\phi_1 = 0 \end{aligned} \tag{5.32}$$

If ϕ_3 equals zero, the minor principal axis is directed vertical in which case $\cos\phi_1$ and $\cos\phi_2$ equal zero; therefore, the quantity $\cos(\theta_1 - \theta_2)$ also equals zero, i.e. the major and intermediate principal axes are directed horizontal and the angle between them is set at 90°. In the upper diagrams of Fig. 5.6, the time dependent directions of principal axes are prescribed along with the direction to the possible epicenter which is indicated by a long-dashed straight line. As observed in these diagrams, the major principal axis which is shown by a solid line is prescribed to be directed to the epicenter, N30°E, during the high intensity motion and the major and intermediate principal axes are assumed to change their positions with each other after the period of high intensity motion. It should be pointed out the horizontal direction angle θ_i when the corresponding angle ϕ_i equals zero does not play a significant role in the transformation matrix.

2. Presentation of Examples

Using a digital computer, four sample accelerograms are produced along a set of principal axes having properties of spectral density

and deterministic intensity as shown in Fig. 5.6. A set of structural principal axes is assumed to be directed to the North-South, East-West and vertical directions. Assuming the horizontal and vertical direction angles of principal axes to be time dependent as represented in Fig. 5.6, the simulated components along the principal axes are transformed to three components of motion along the assumed axes of the structural system. The resulting components of motion are shown in Figs. 5.7a through 5.7d, respectively.

Assuming that these accelerograms were recorded by an accelerograph installed in the structural system and applying the identical computer routines which have been used to analyze the ground motions of the San Fernando earthquake, principal variances, directions of principal axes and frequency content of motion along the principal axes are evaluated. The resulting properties of principal variances and directions of principal axes are presented in Figs. 5.8a through 5.8d and the corresponding time dependency of frequency content are represented in Figs. 5.9a through 5.9d, respectively. These diagrams are plotted in identically the same manner as those previously shown for the accelerograms recorded during the San Fernando earthquake.

3. Observation of Results

In this investigation, only four samples of the simulated ground motion process are presented. Their characteristics in terms of principal variances and directions of principal axes, and frequency content coincide well with the prescribed properties. Several features can be noted for these samples as follows:

(1) The direction of the major principal axis oscillates and sometimes can deviate up to 30° from the prescribed direction which is towards the expected epicenter.

(2) At the end of sample records when the intensities of motion are small, the directions of principal axes approach N60°W and N30°E which coincides well with the prescribed directions.

(3) The sudden interchange of directions of the major and intermediate principal axes can be explained by the cross-over in their intensities as measured by principal variances.

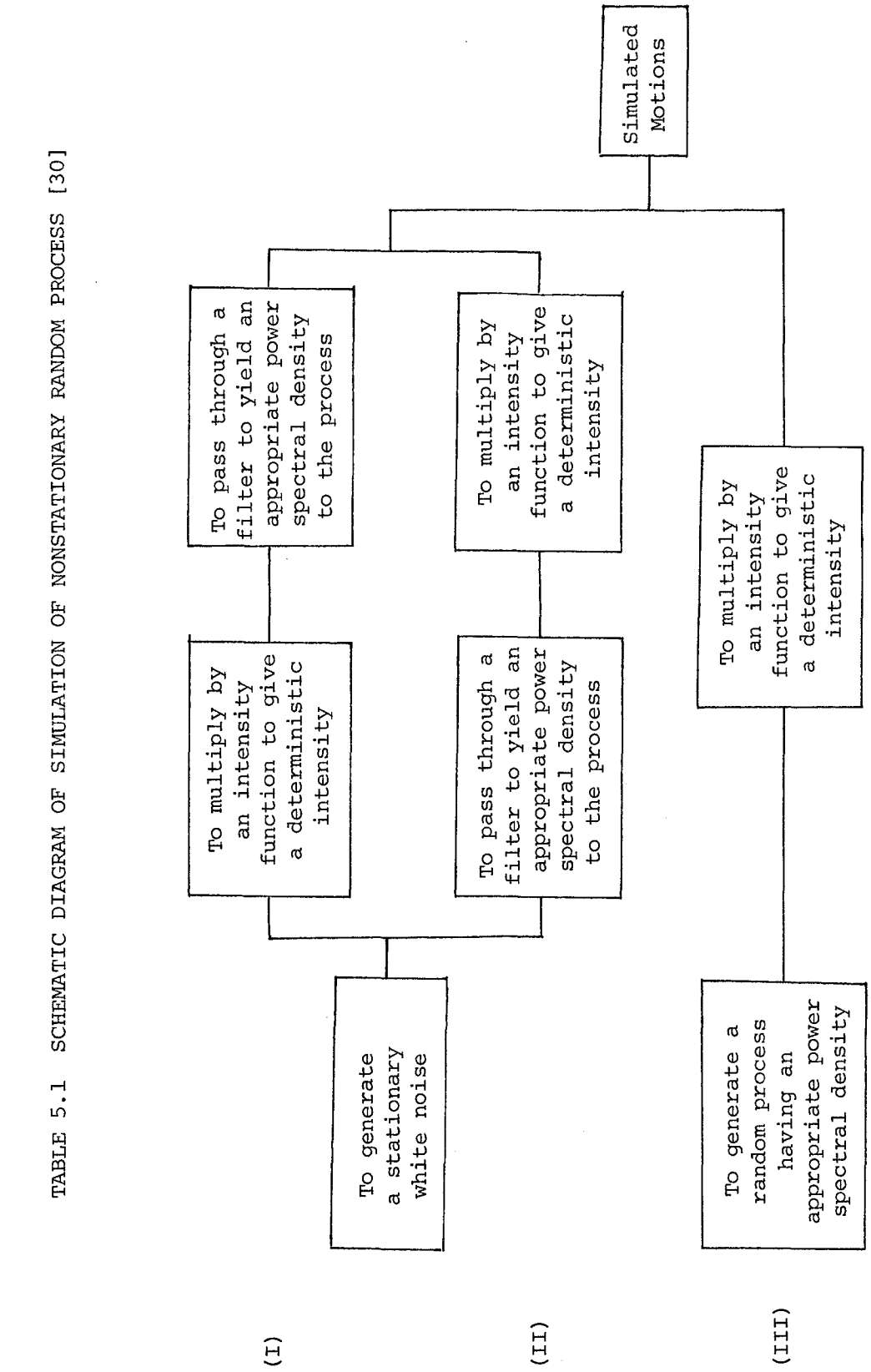
(4) The direction of the minor principal axis which is prescribed to be vertical happens to be nearly horizontal during the later period of motion when the minor and intermediate principal variances approach each other in value; thus, allowing the interchange of position to take place. This same behavior can be observed for recorded motions, especially, for those obtained within high-rise buildings near the epicenter.

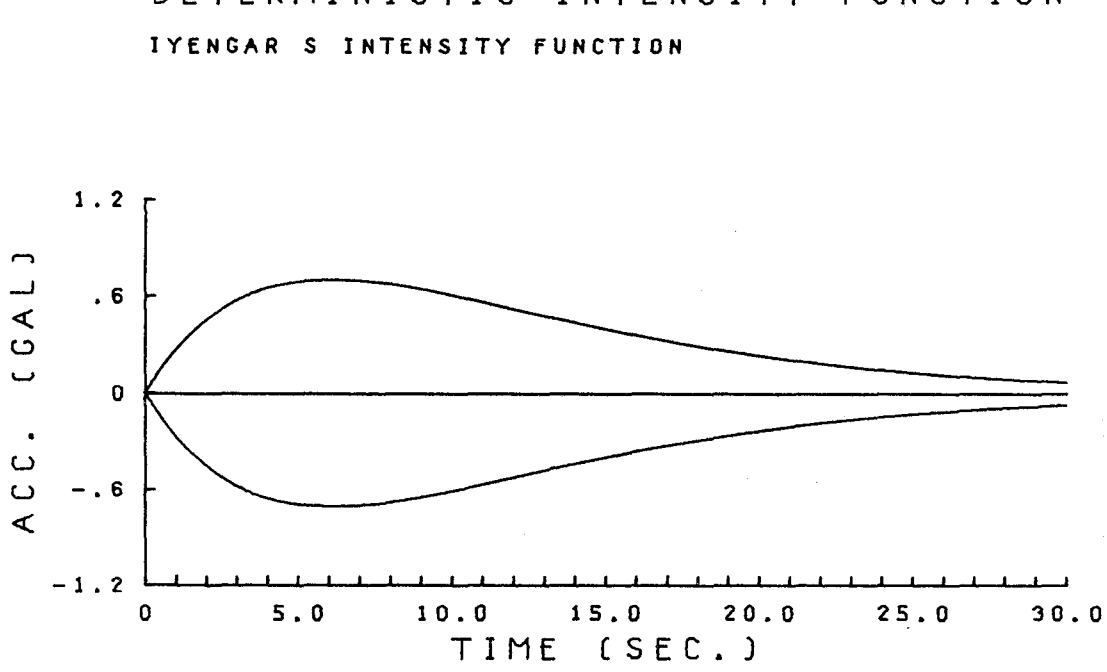
(5) Since the actual direction of the minor principal axis shifts slightly from its prescribed vertical position, its horizontal direction can easily take any position; thus, the horizontal direction of the minor principal axis is observed to oscillate significantly. Generally, however, the horizontal direction of the minor principal axis unexplainably coincides with that of the intermediate principal axis over large periods of duration; see sample No. 3.

(6) Even though the filtering procedure using convolution weights was applied twenty times, the evaluated spectral density shapes oscillate irregularly. The general characteristics of frequency content as prescribed, however, are suitably reproduced.

As indicated by the above observations, the properties of the simulated motions reveal complexities similar to the characteristics of the real motions recorded during the San Fernando earthquake. Therefore, the simple ground motion model prescribed appears to be adequate.

TABLE 5.1 SCHEMATIC DIAGRAM OF SIMULATION OF NONSTATIONARY RANDOM PROCESS [30]





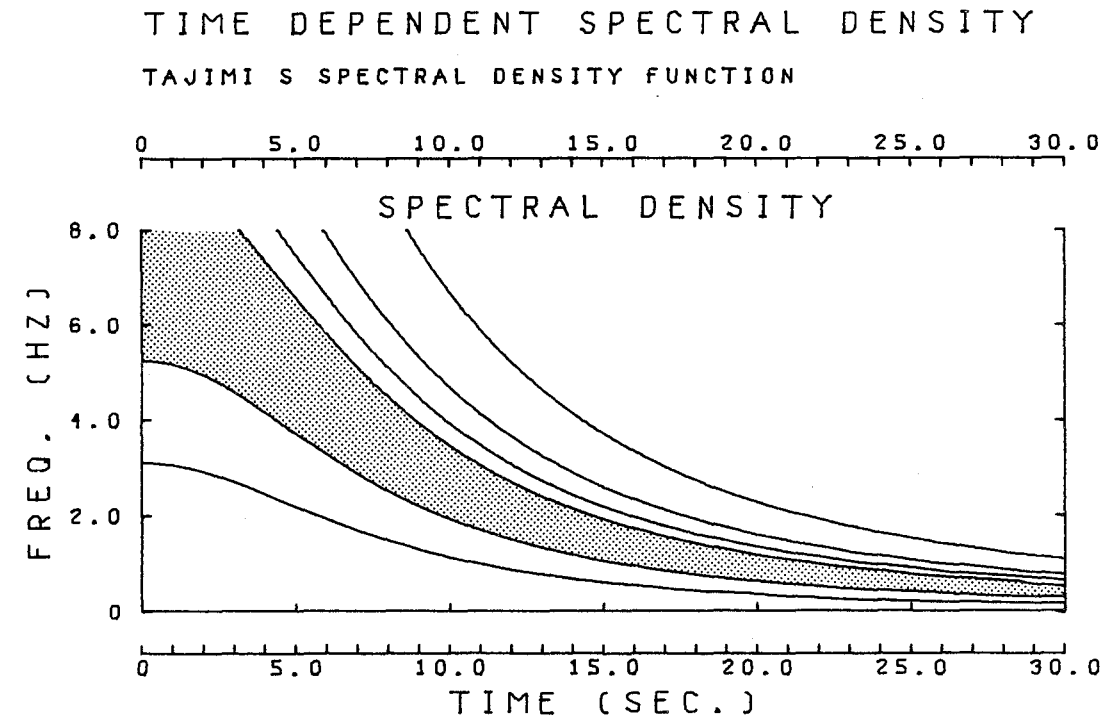
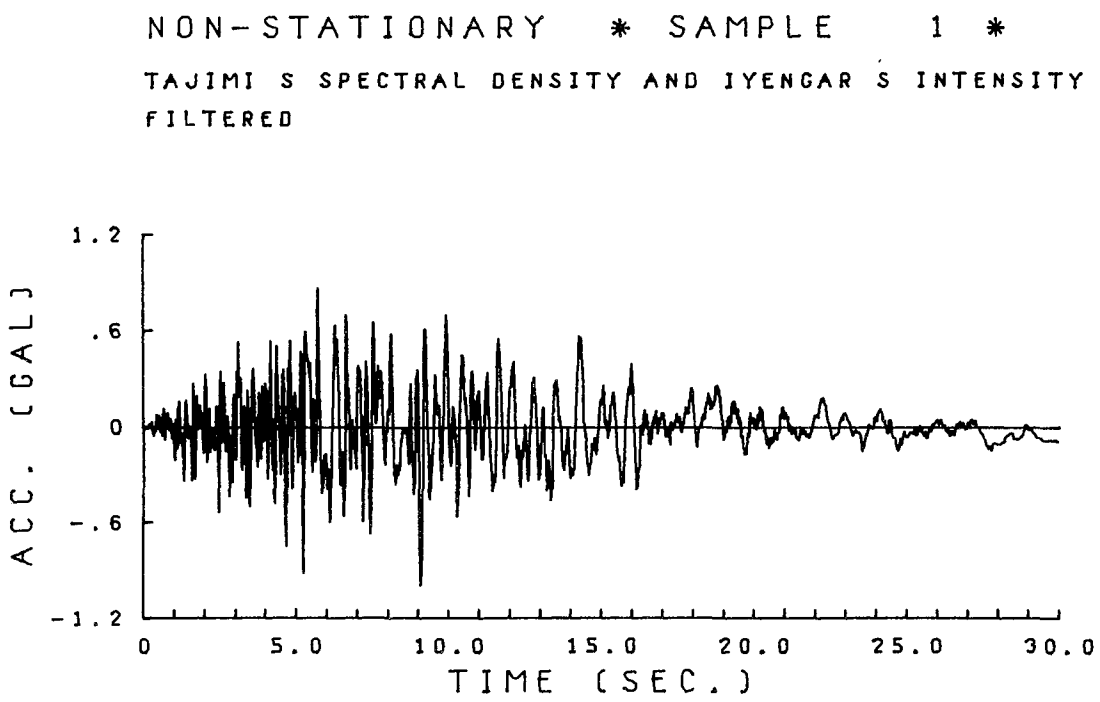


Fig. 5.1 Prescribed intensity and spectral density function.



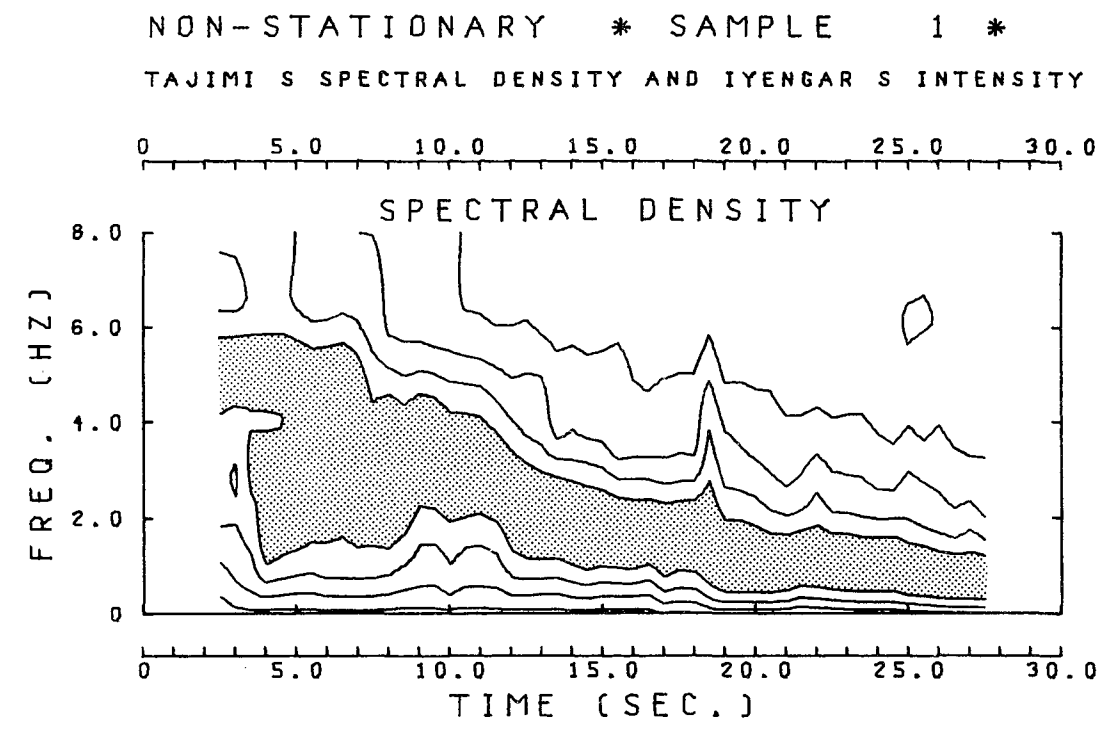


Fig. 5.2 Time history and time dependent spectral density for sample 1.

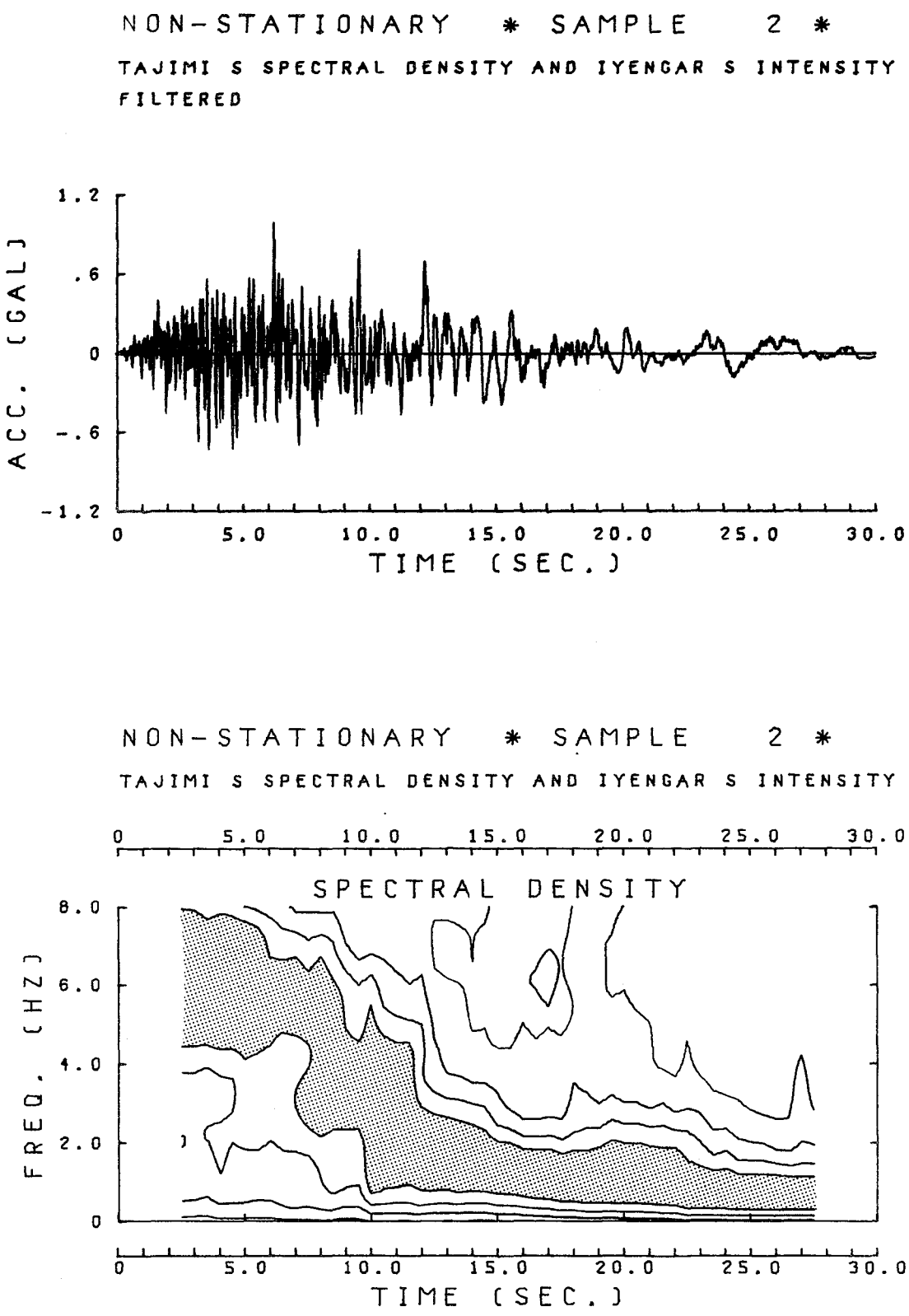


Fig. 5.3 Time history and time dependent spectral density for sample 2.

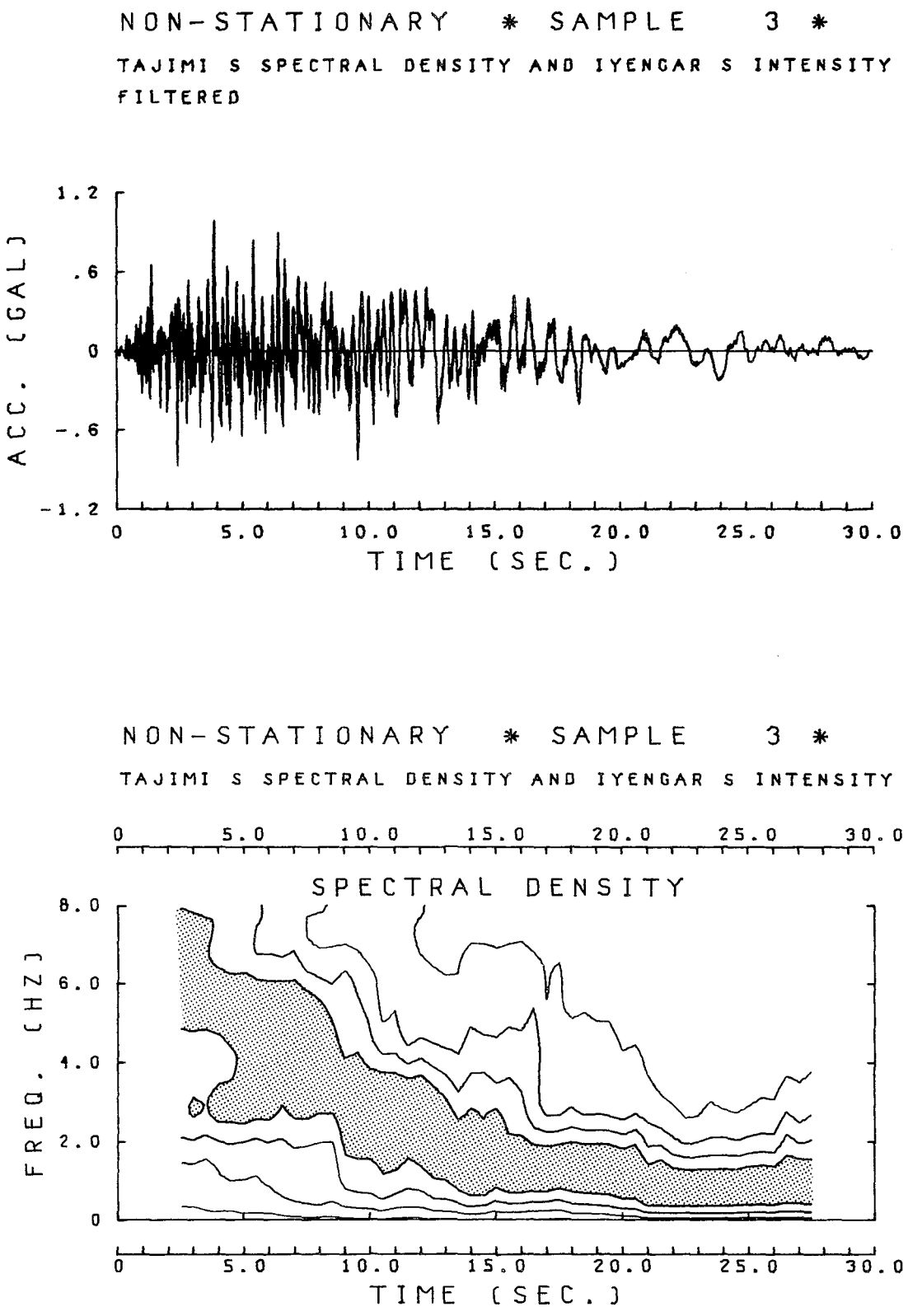
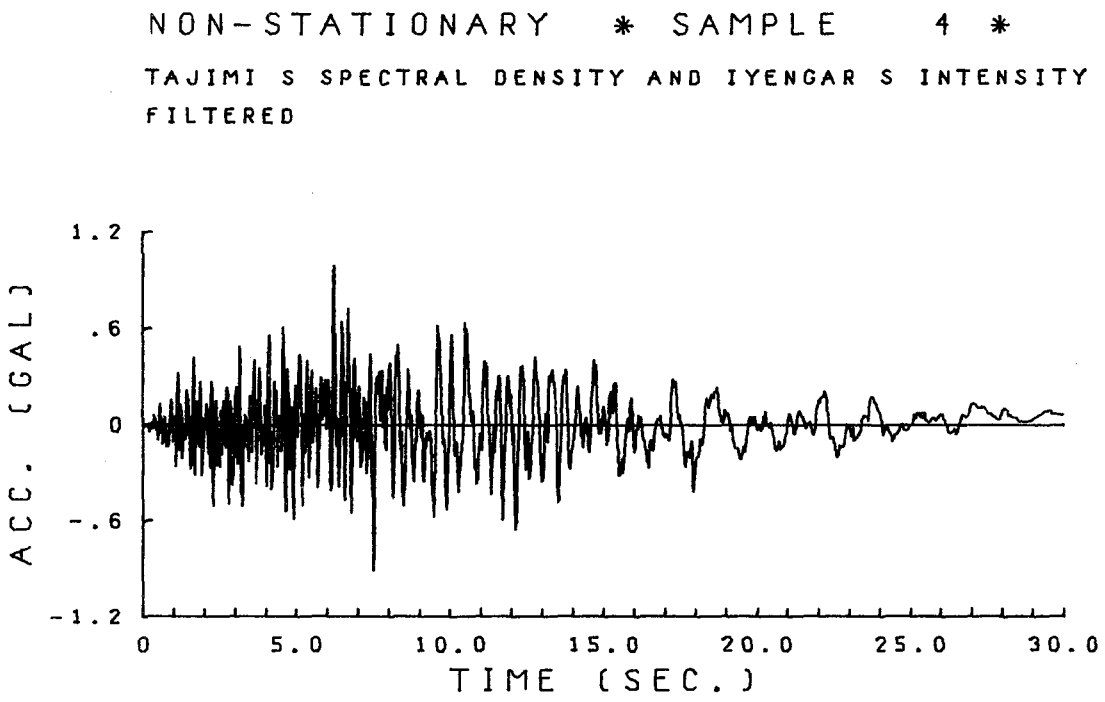


Fig. 5.4 Time history and time dependent spectral density for sample 3.



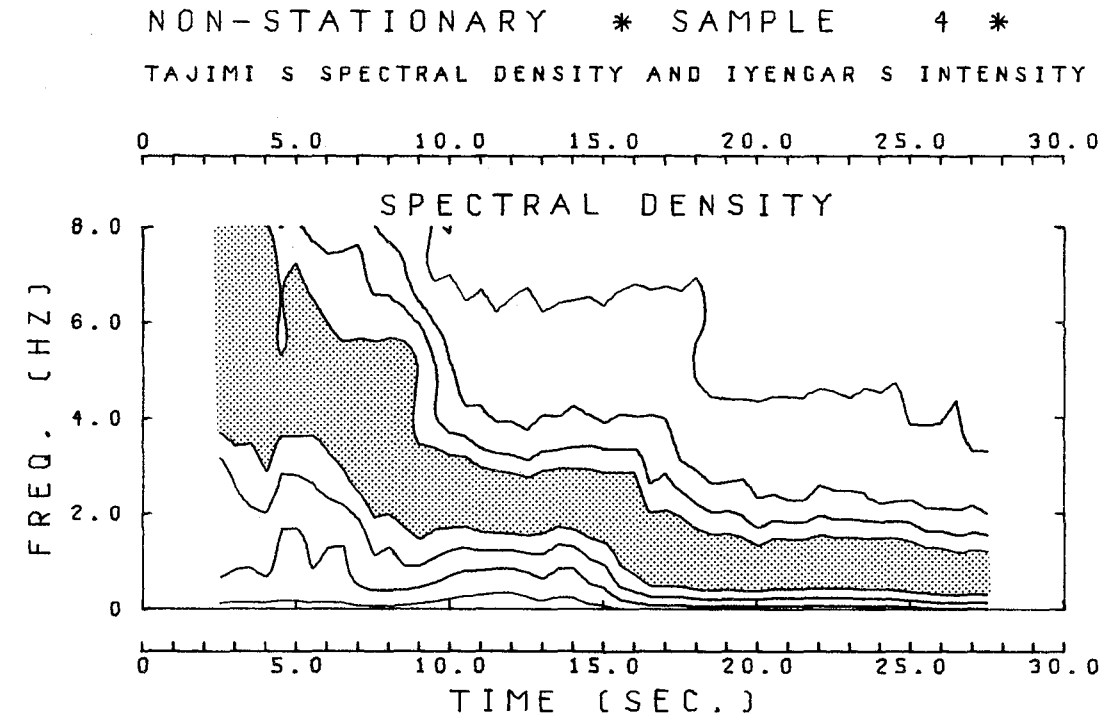


Fig. 5.5 Time history and time dependent spectral density for sample 4.

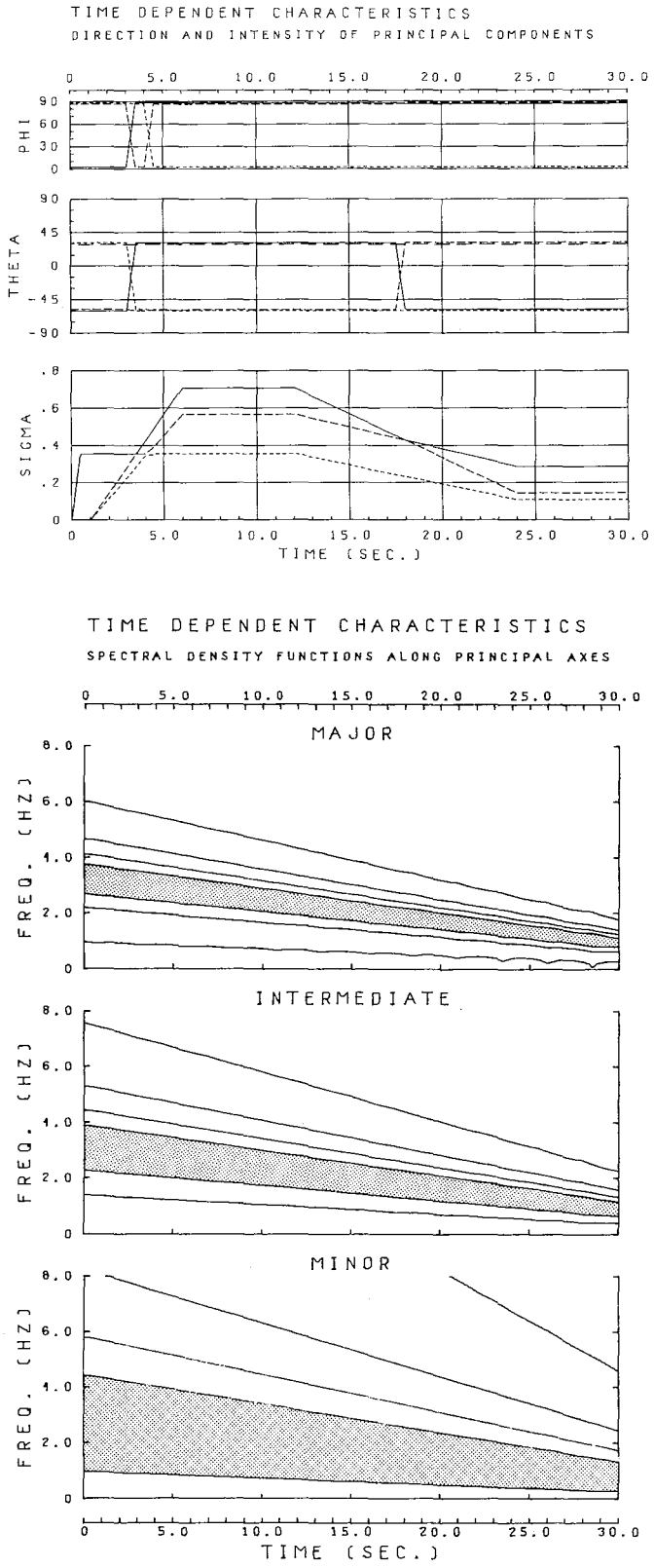


Fig. 5.6 Prescribed properties of three-dimensional stochastic model.

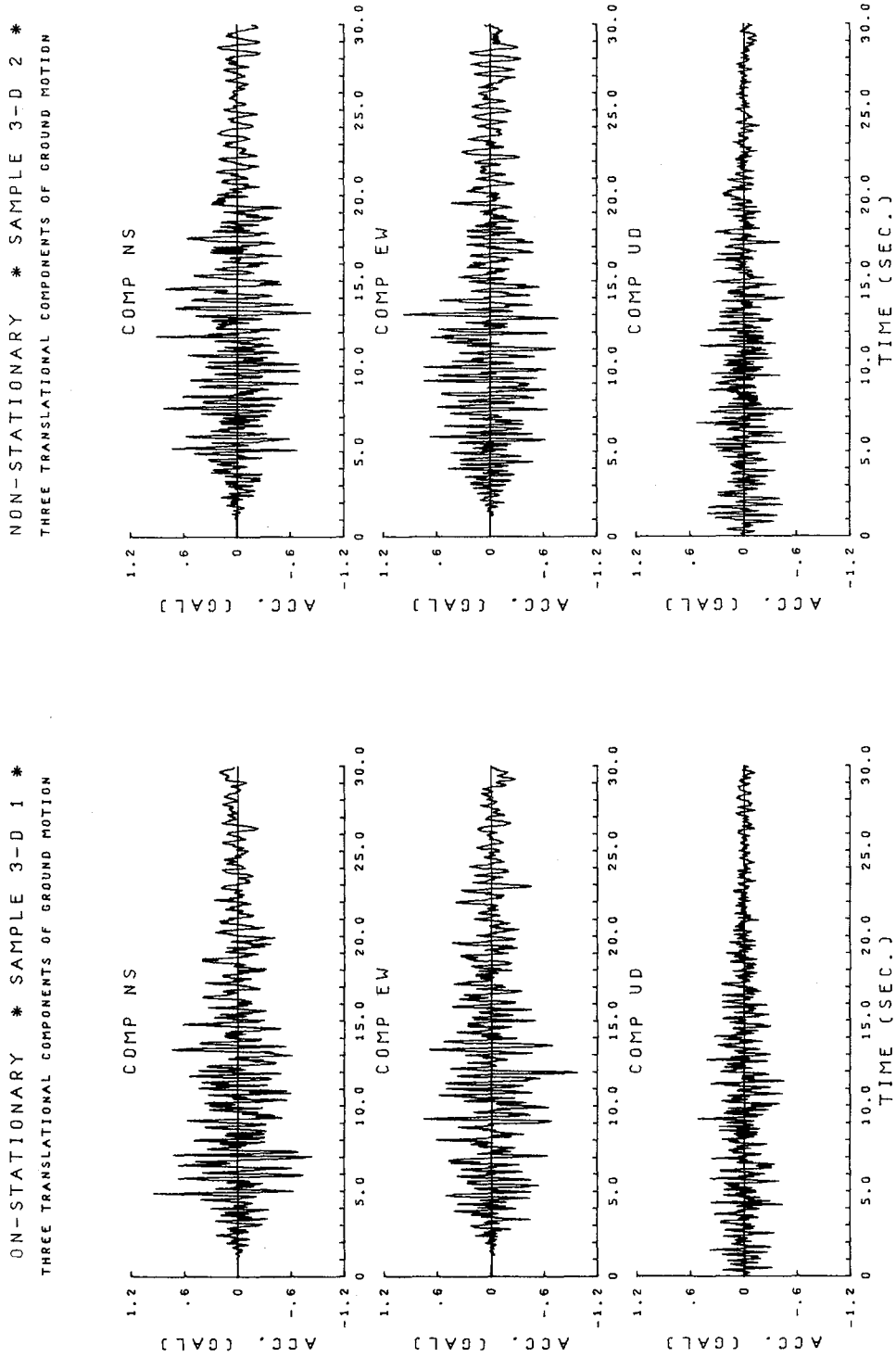


Fig. 5.7 Time histories of simulated accelerogram.

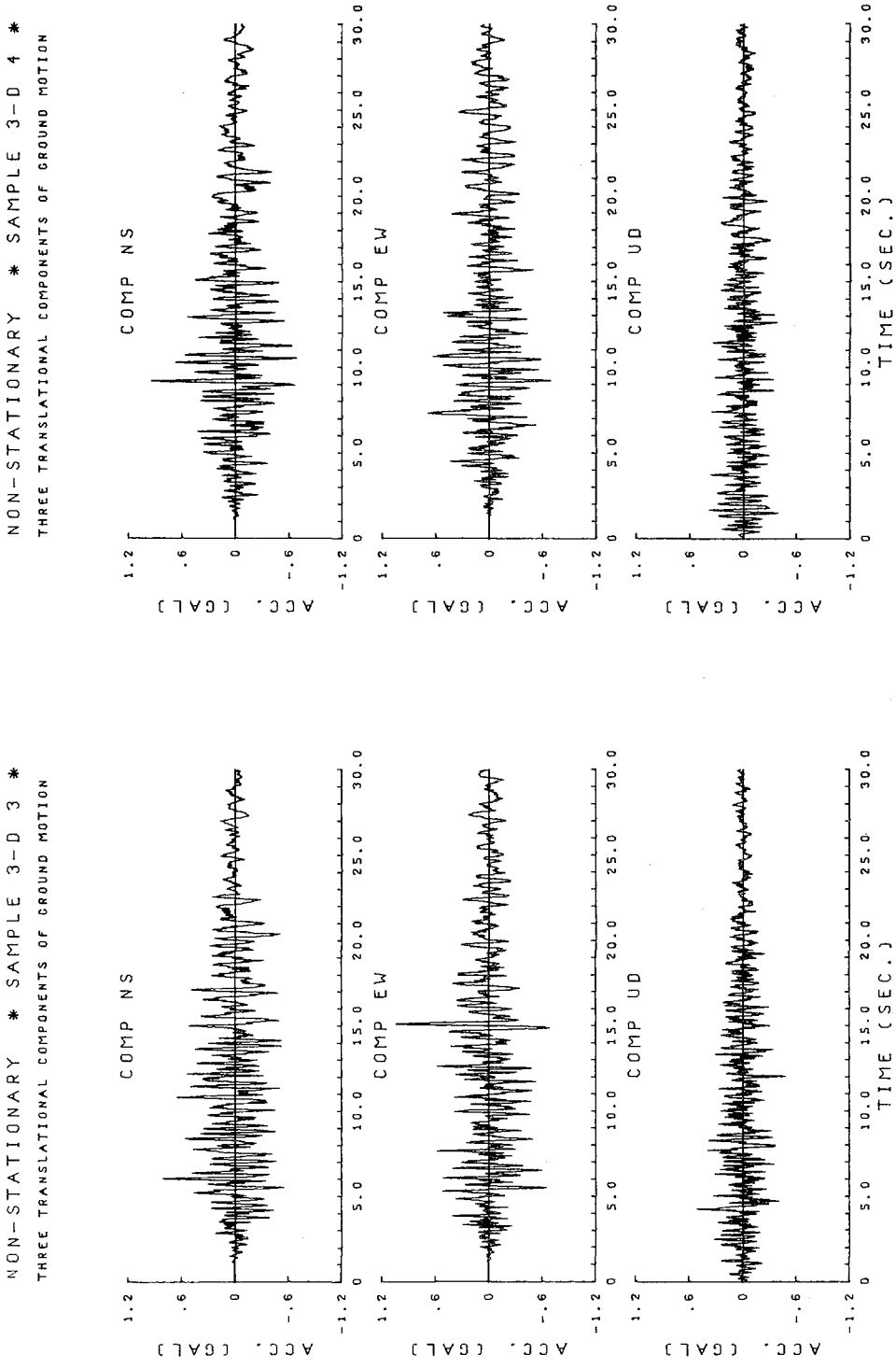


Fig. 5.7 (continued)

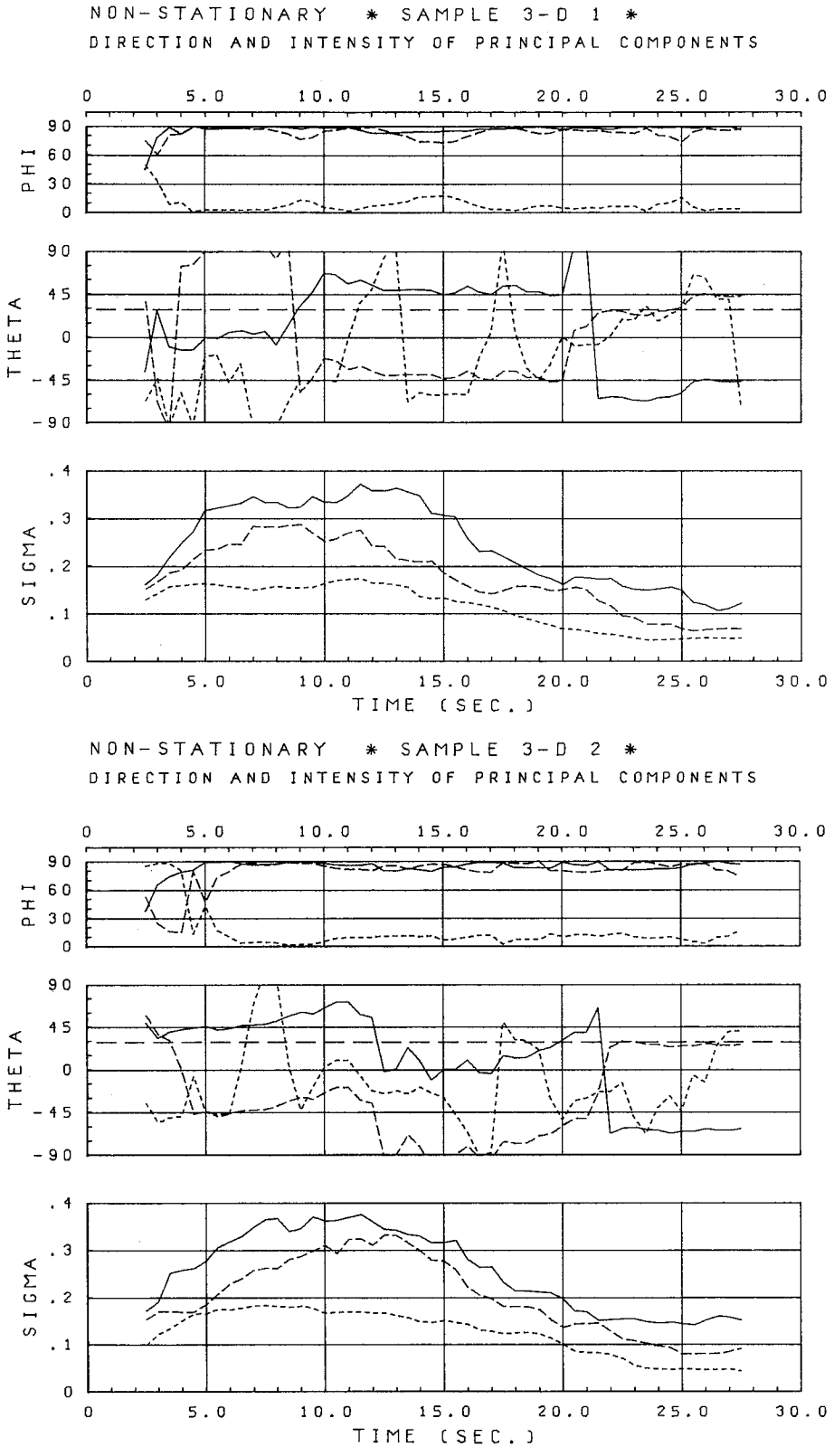
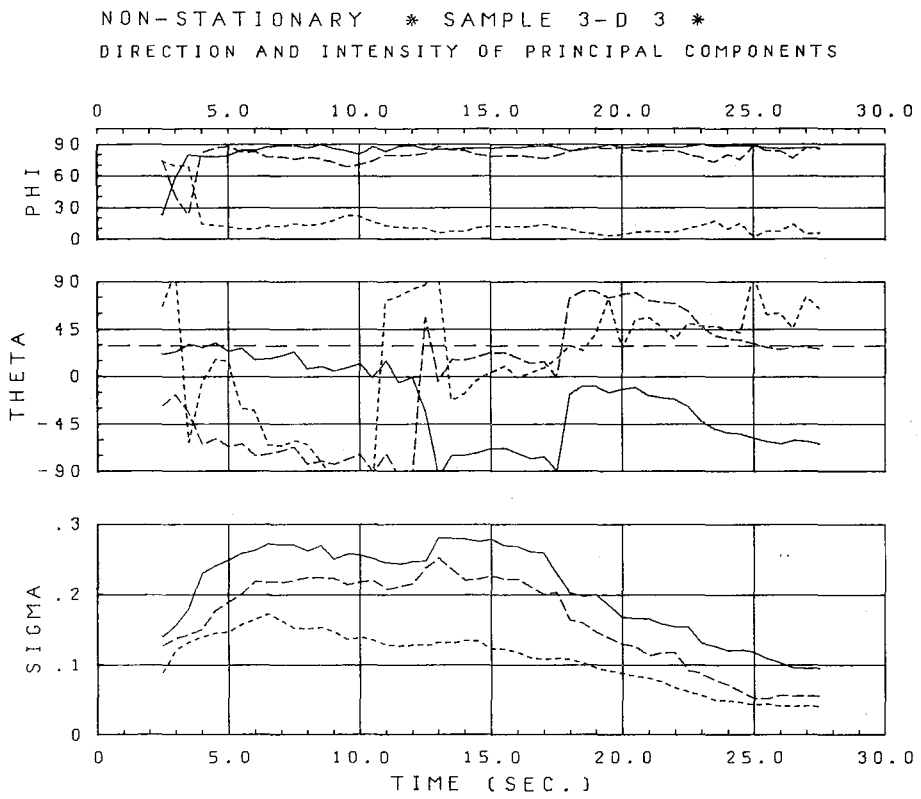


Fig. 5.8 Time dependent directions of principal axes and square root of principal variances for simulated motions.



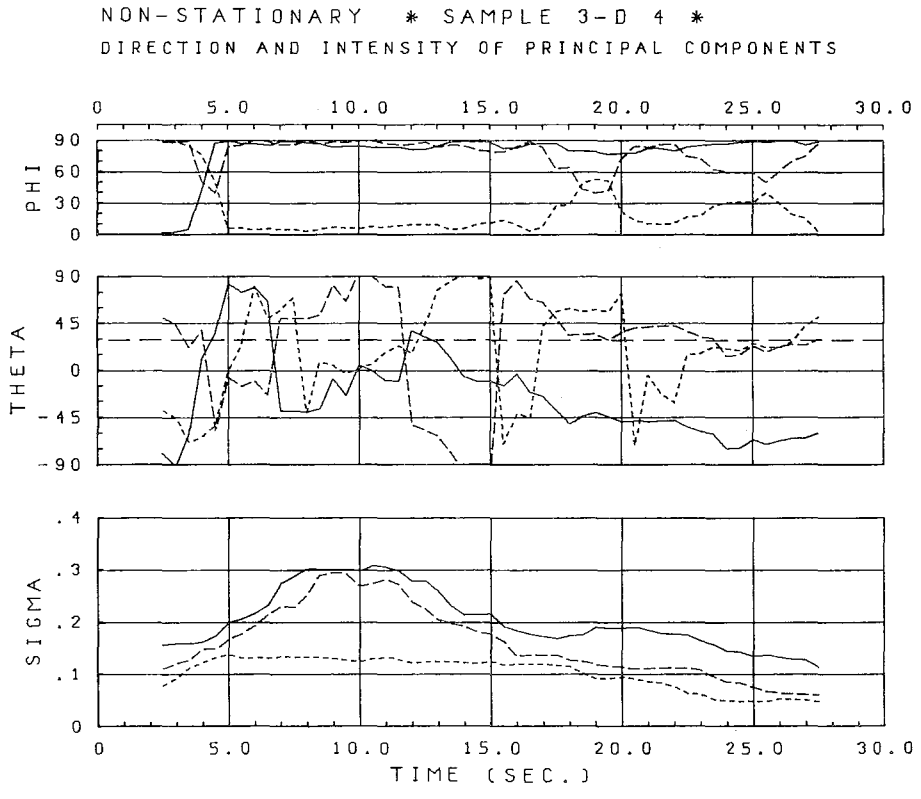


Fig. 5.8 (continued)

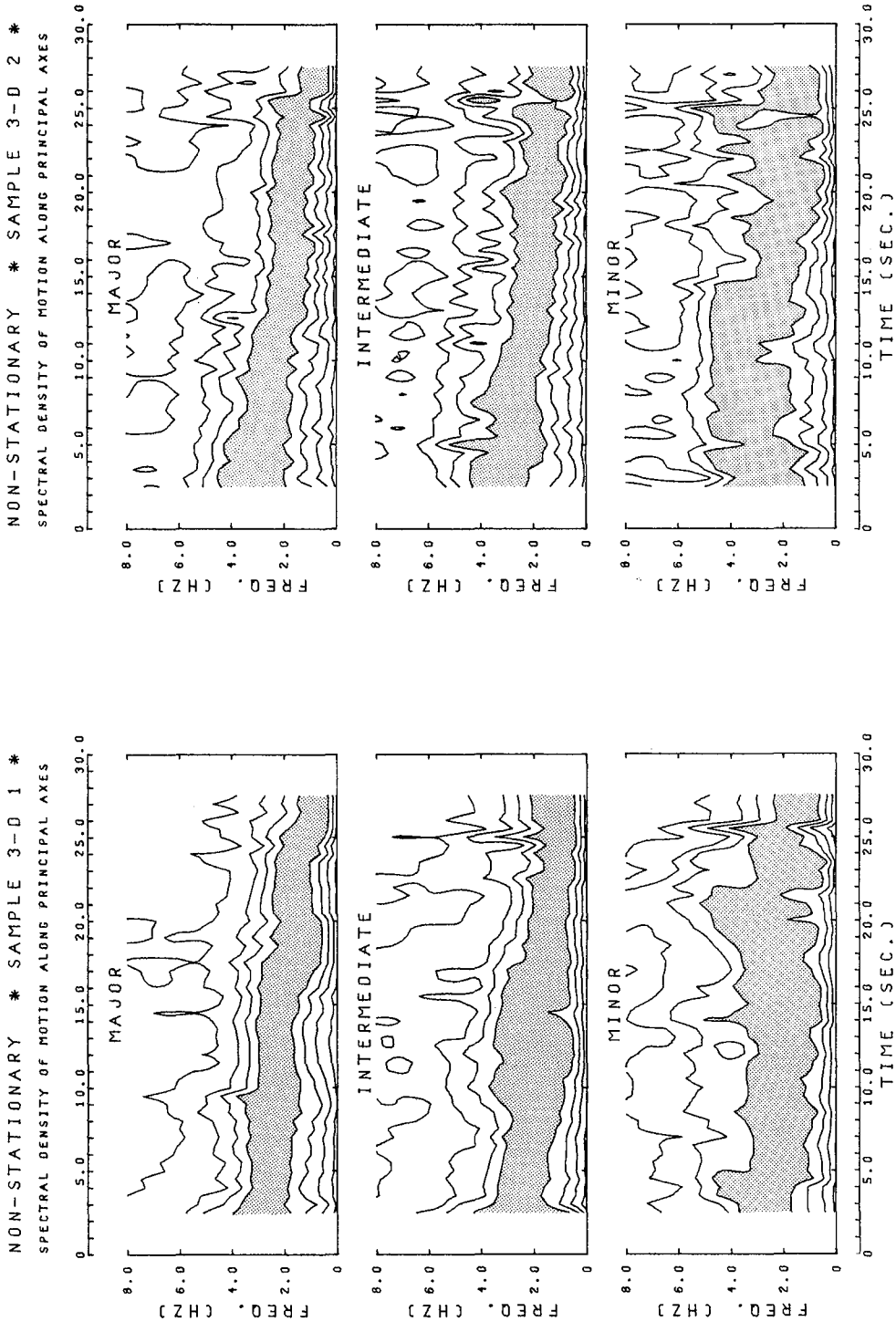


Fig. 5.9 Time dependent frequency distribution for simulated motions.

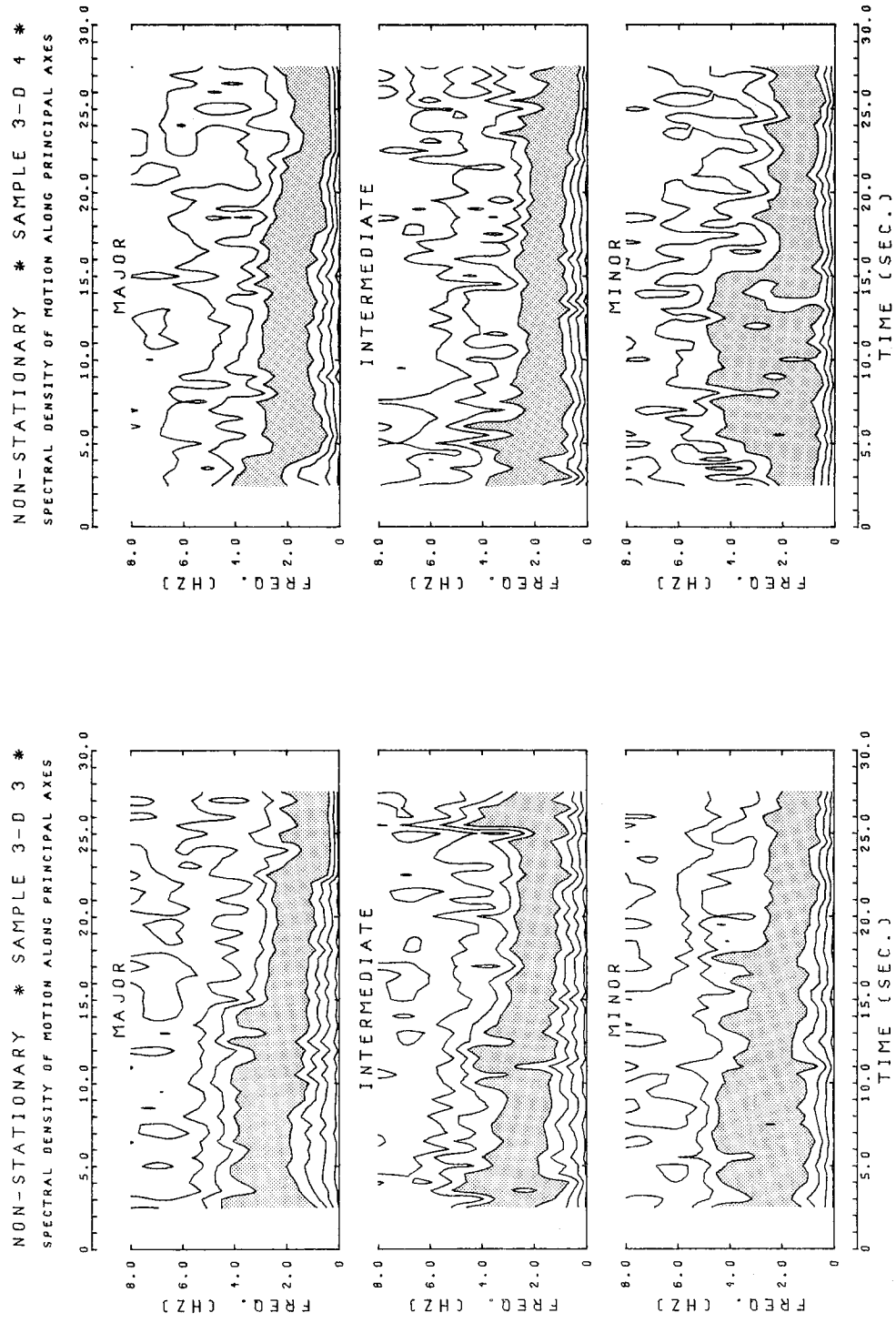


Fig. 5.9 (continued)

VI. CONCLUDING STATEMENT

This report presents the results of an analysis of the three-dimensional ground motions recorded during the San Fernando earthquake of February 9, 1971. The methods adopted make use of the concept of principal axes of ground motion and the moving-window technique in both the time and frequency domains.

The objective of the analysis is to establish a stochastic model for three-dimensional ground motions which reflects the significant statistical properties of the motions recorded during the San Fernando earthquake. Because of the existance of principal axes, the three components of motion are statistically independent, provided they are directed along a set of principal axes. The resulting model is represented by the product of a deterministic intensity function and a constant intensity process having a variable frequency content with time.

It is believed that the general form of the model developed herein represents an improvement over that most commonly used, i.e. the product of a deterministic intensity function and a stationary process. One must be careful, however, in assuming that the quantitative form of this model would apply to the motions produced by other earthquakes even when their magnitudes and epicentral distances are similar to those of the San Fernando earthquake. Only by conducting studies similar to those reported herein for future earthquake motions can the quantitative differences and their causes be determined.

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48. Trifunac, M. D., A. G. Brady and D. E. Hudson
"Strong Motion Earthquake Accelerograms, Digitized and Plotted Data," Volume II-Corrected Accelerograms and Integrated Ground Velocity and Displacement Curves, Part C - S, Report of Earthquake Engineering Research Laboratory, California Institute of Technology, Pasadena, California.

49. Trifunac, M. D.
"Introduction to Volume II," in "Strong Motion Earthquake Accelerograms, Digitized and Plotted Data," Volume II, Part A, Report of Earthquake Engineering Research Laboratory, EERL 71-50, California Institute of Technology, Pasadena, California, September 1971.

50. Trifunac, M. D. and V. Lee
"Routine Computer Processing of Strong-Motion Accelerograms," Report of Earthquake Engineering Research Laboratory, EERL 73-03, California Institute of Technology, Pasadena, California, October 1973.

51. Trifunac, M. D. and A. G. Brady
"Correlations of Peak Acceleration with Intensity," Bulletin of the Seismological Society of America, Vol. 65, No. 1, February 1975.

APPENDIX A

Results of (i) time dependent directions of principal axes and square root of principal variances, (ii) frequency dependent directions of principal axes and square root of principal variances, (iii) time dependent principal variances and principal cross correlation coefficients, and (iv) time dependent frequency distribution for motions in area F.

TABLE A.1 ACCELEROGRAPH SITE INFORMATIONS - AREA F [29]

STATION ID NUMBER*	STATION LOCATION	POSITIVE DIRECTION OF ACCELEROGRAPH	PEAK ACC. (GAL)	APPROX. DISTANCE TO EPICENTER (KM)	DIRECTION TO EPICENTER** (DEGREE)	BUILDING STRUCTURAL TYPE	ABBREVIATED SITE GEOLOGY ( )***
157	445 Figueroa St Subbasement	N52W S38W DOWN	147.1 -117.0 51.7	40.6	-18	39-story St. Building	Shale (S)
154	420 South Grand Ave. 2nd Floor****	S53E S37W DOWN	-168.3 116.1 - 56.5	41.1	-19	16-story St. Building	Shale and Siltstone several 1000' (S)
160	535 South Fremont Ave. Basement	N30W S60W UP	242.0 -220.7 81.7	40.6	-18	10-story RC Building	Alluvium (S)
163	611 West Sixth St. Basement	N38E N52W DOWN	101.9 78.5 53.2	41.1	-18	43-story St. Building	Alluvium (S)
166	646 South Olive Ave. Basement	S53E S37W DOWN	-236.4 -192.0 69.2	41.3	-18	8-level RC Parking Ramp	Alluvium (S)
175	808 South Olive St. Street Level	S53E S37W DOWN	-131.9 -139.0 75.3	42.7	-18	8-level RC Parking Ramp	Alluvium (S)

* Permanent identification number in annual list of stations issued by the Seismological Field Servey, NOS-NOAA

** Direction angles are measured from the north in clockwise.

*** Site classification. (S), (I) and (H) correspond to soft, intermediate and hard site classifications, respectively [51].

**** Second floor is ground level. Floor numbers from adjoining building.

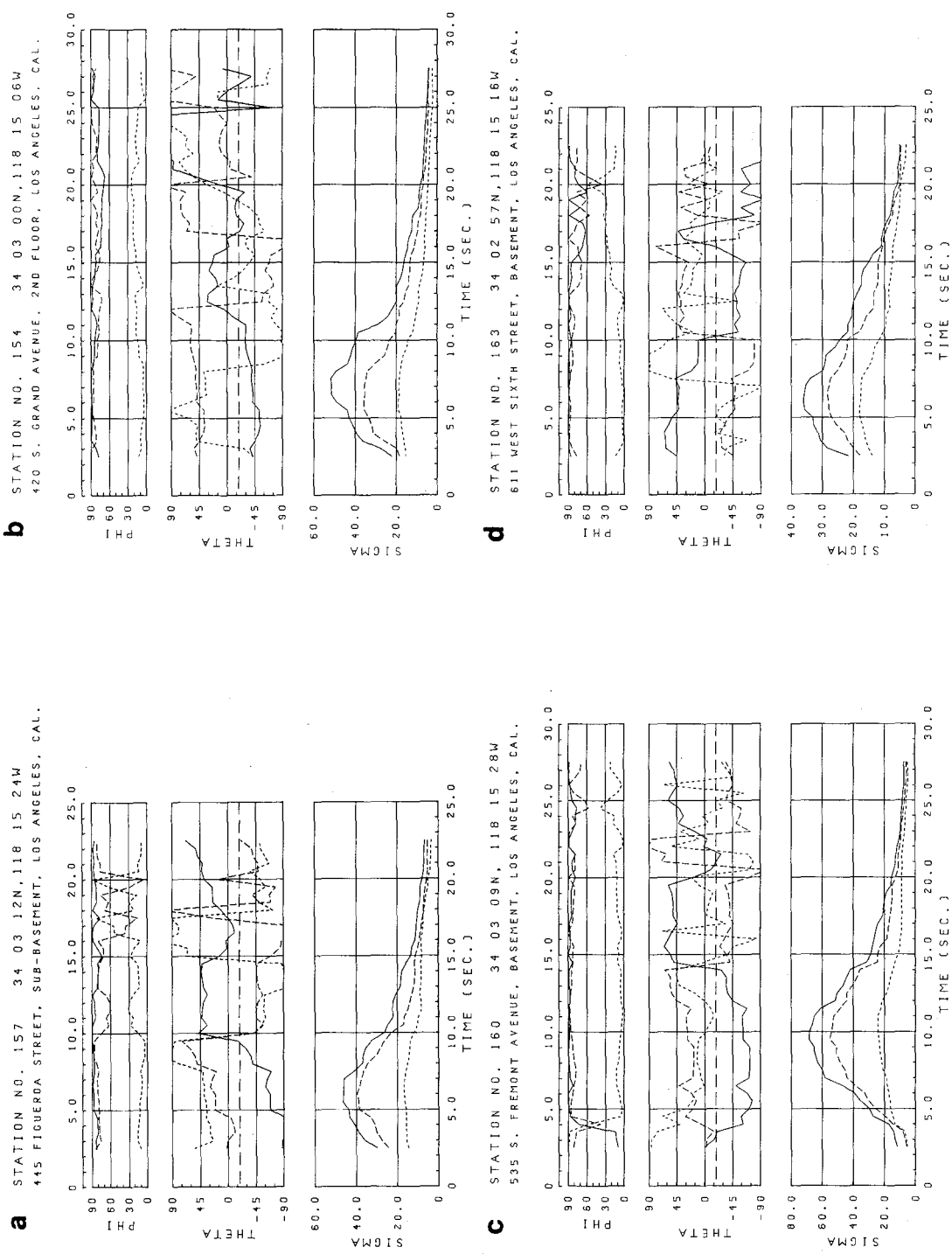


Fig. A.1 Time dependent directions of principal axes and square root of principal variances in area F.

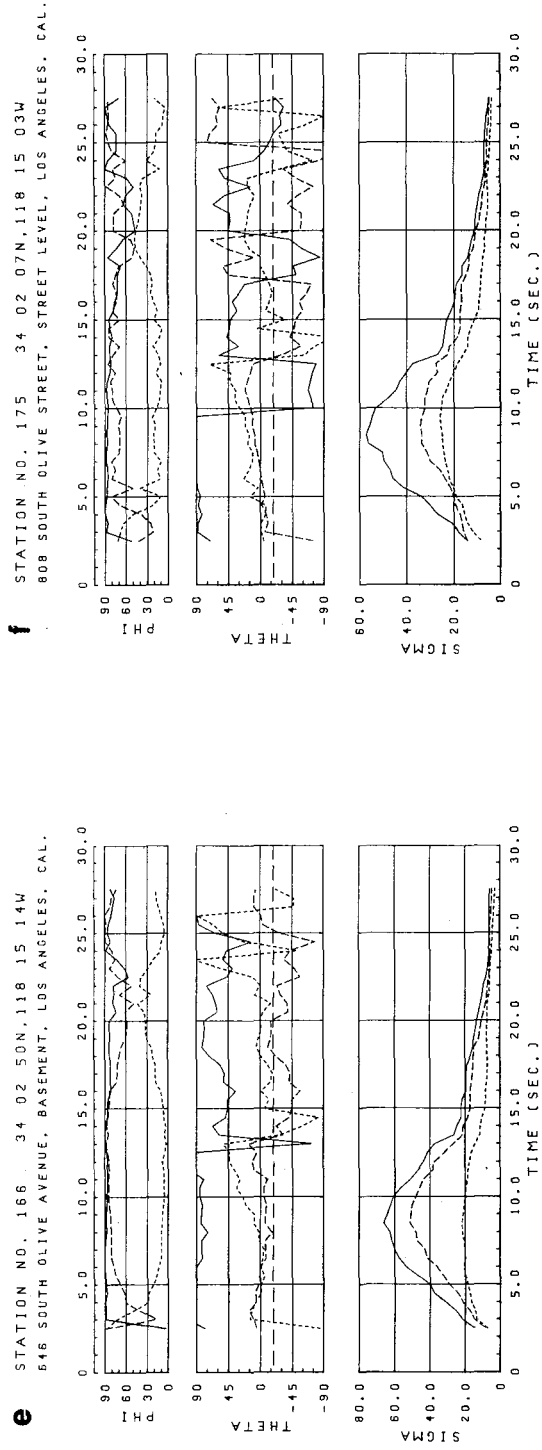


Fig. A.1 (continued)

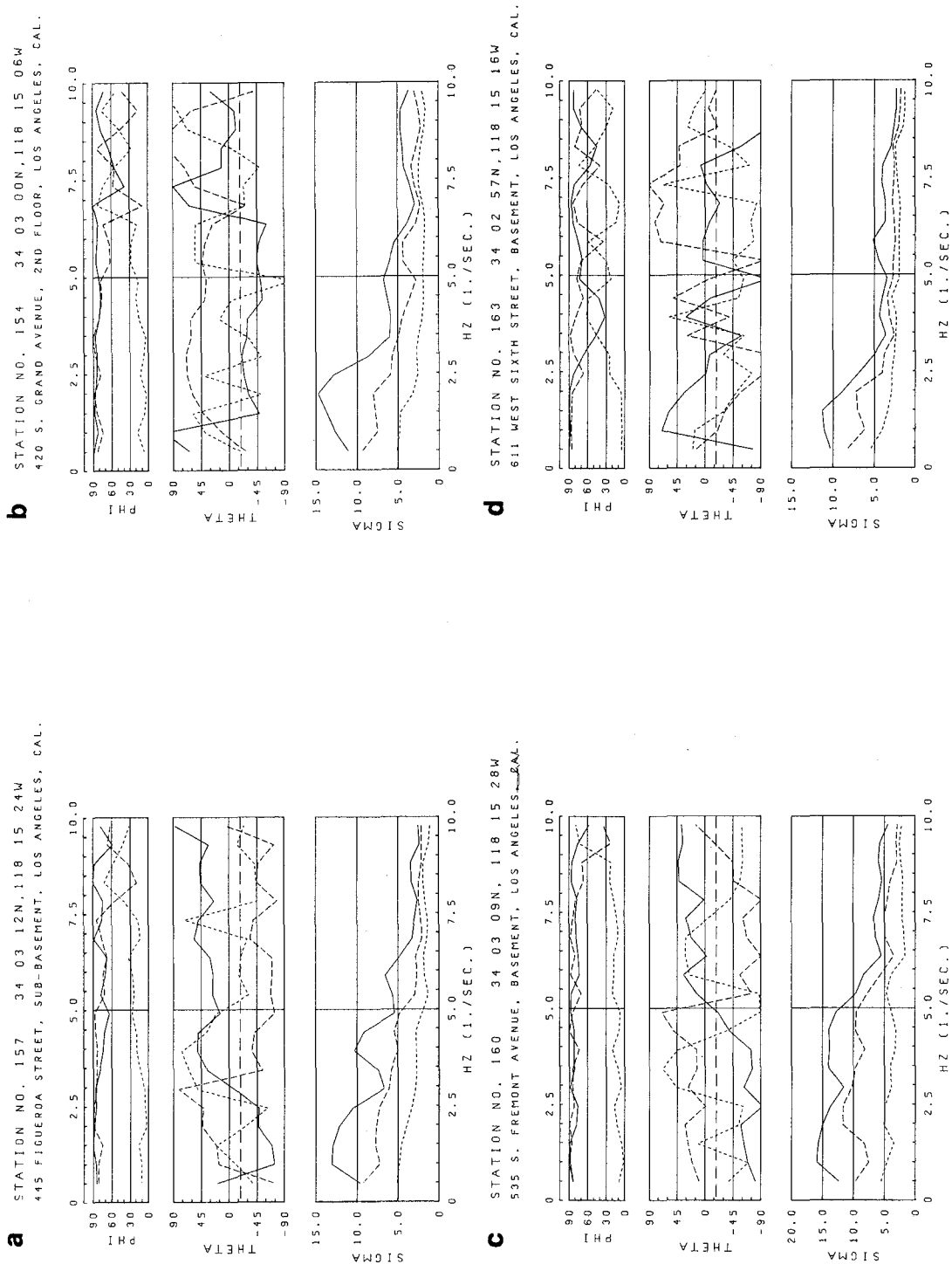


Fig. A.2 Frequency dependent directions of principal axes and square root of principal variances in area F.

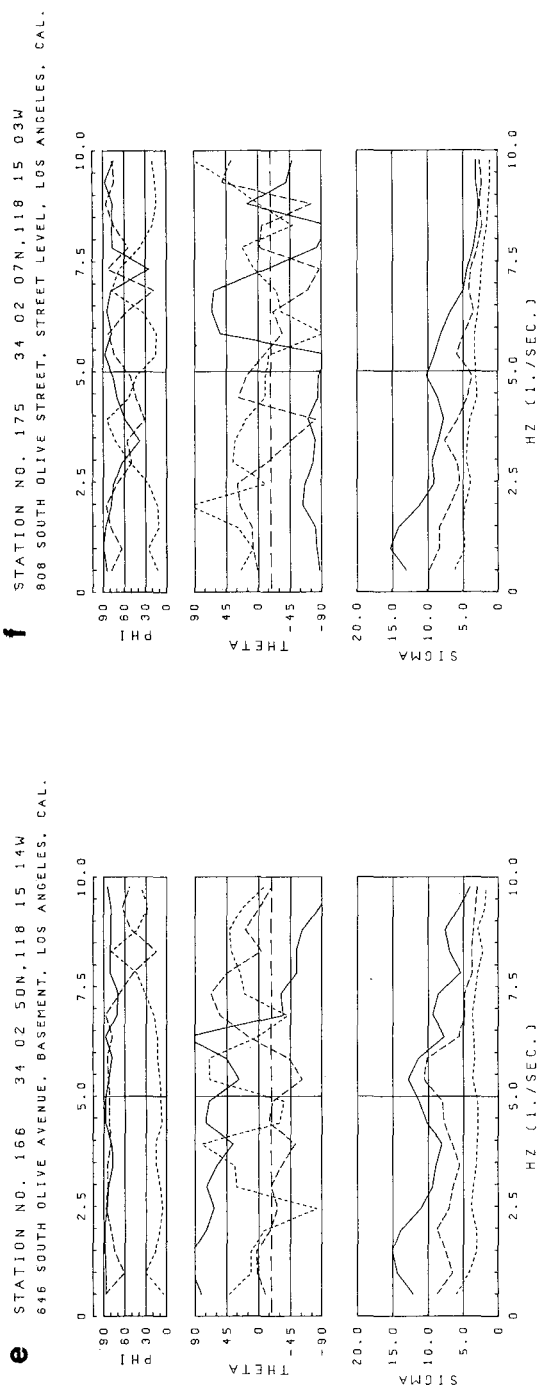


Fig. A.2 (continued)

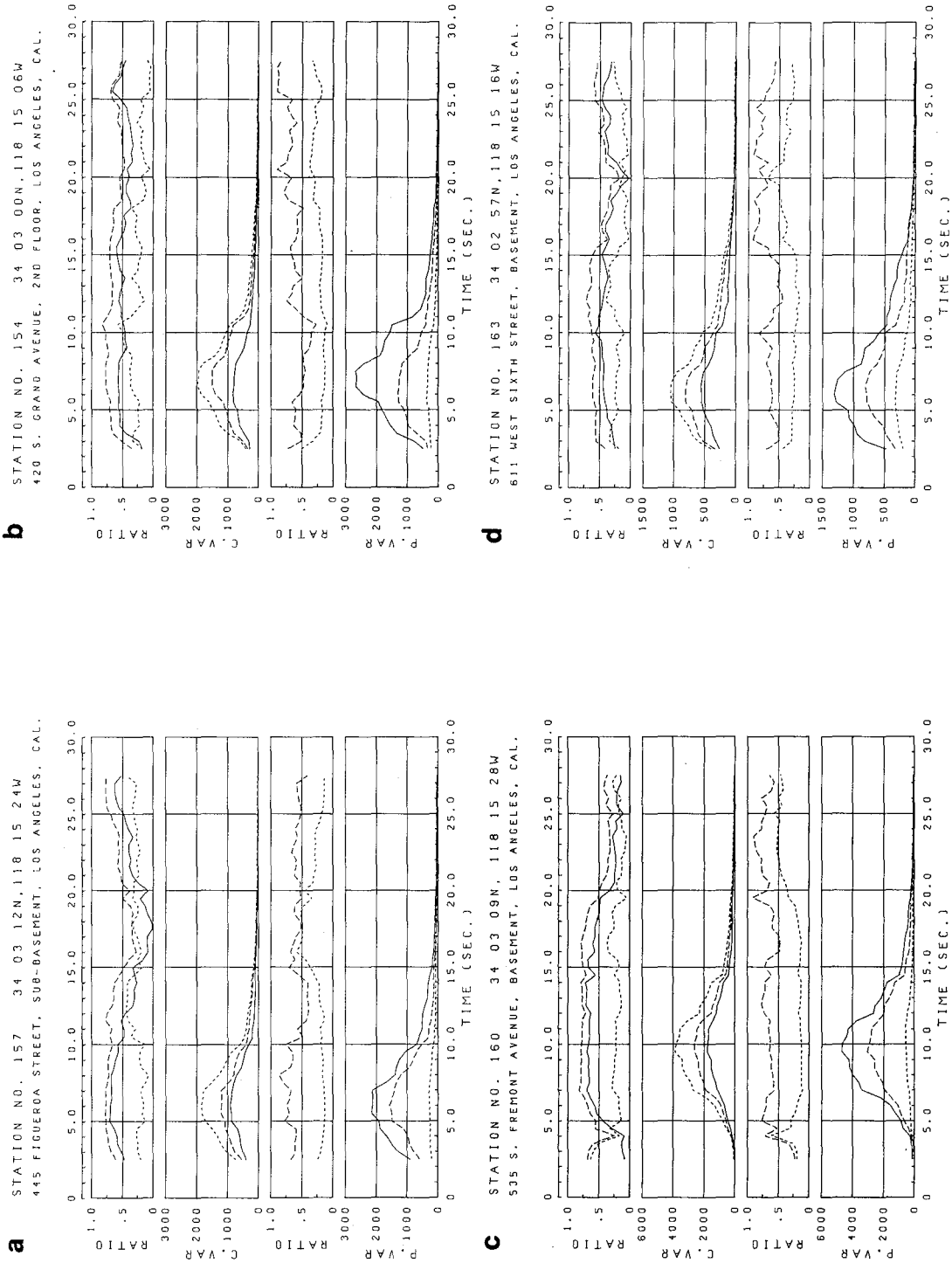


Fig. A.3 Time dependent principal variances and principal cross correlation coefficients in area F.

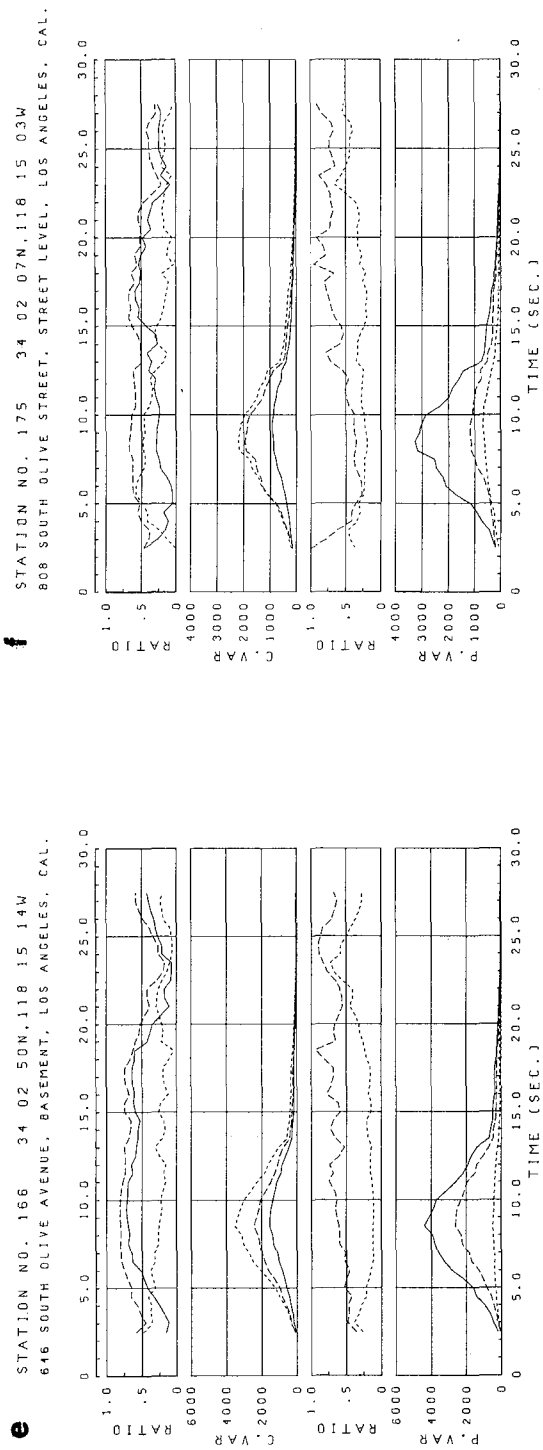


Fig. A.3 (continued)

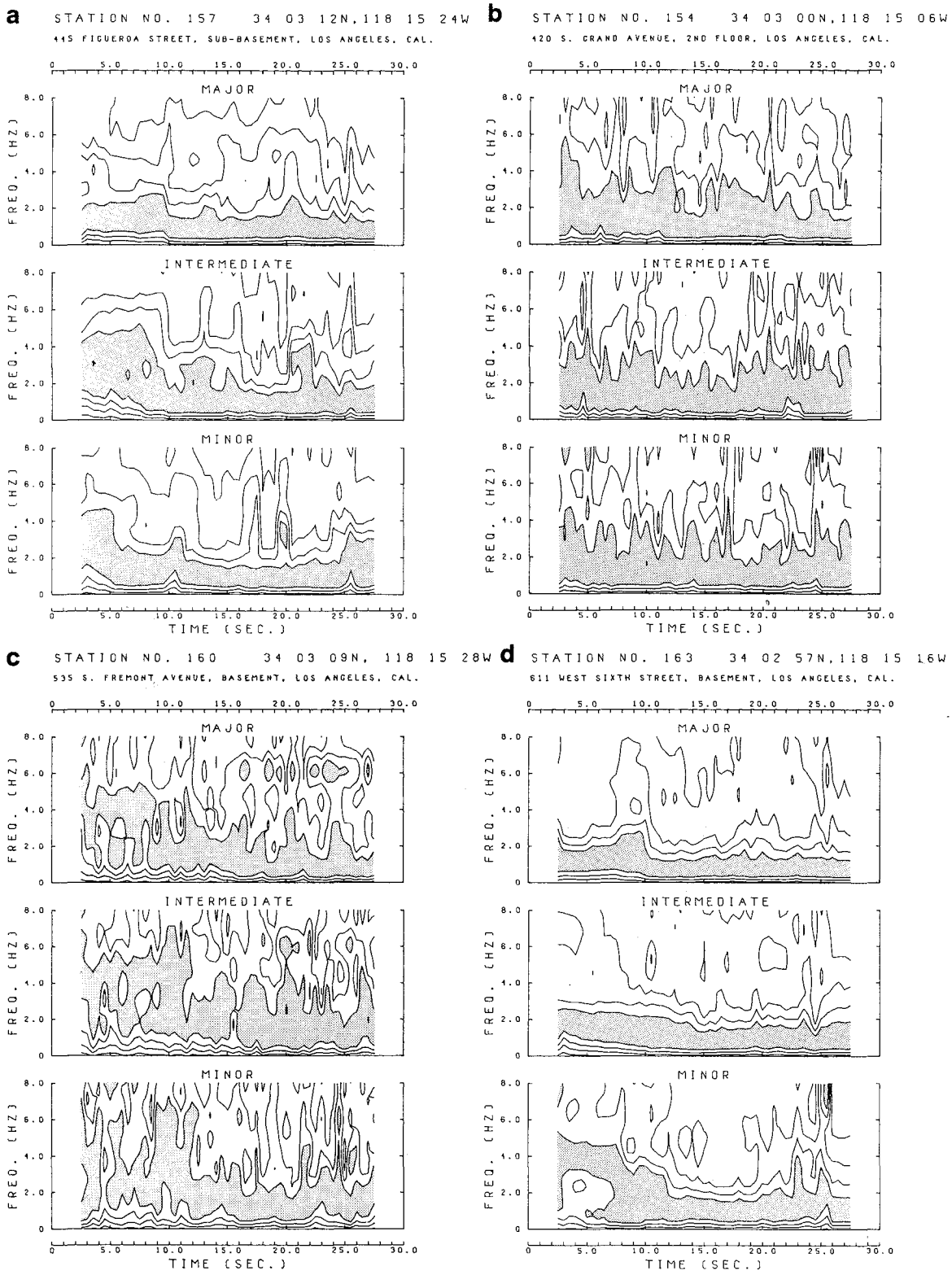


Fig. A.4 Time dependent frequency distribution in area F.

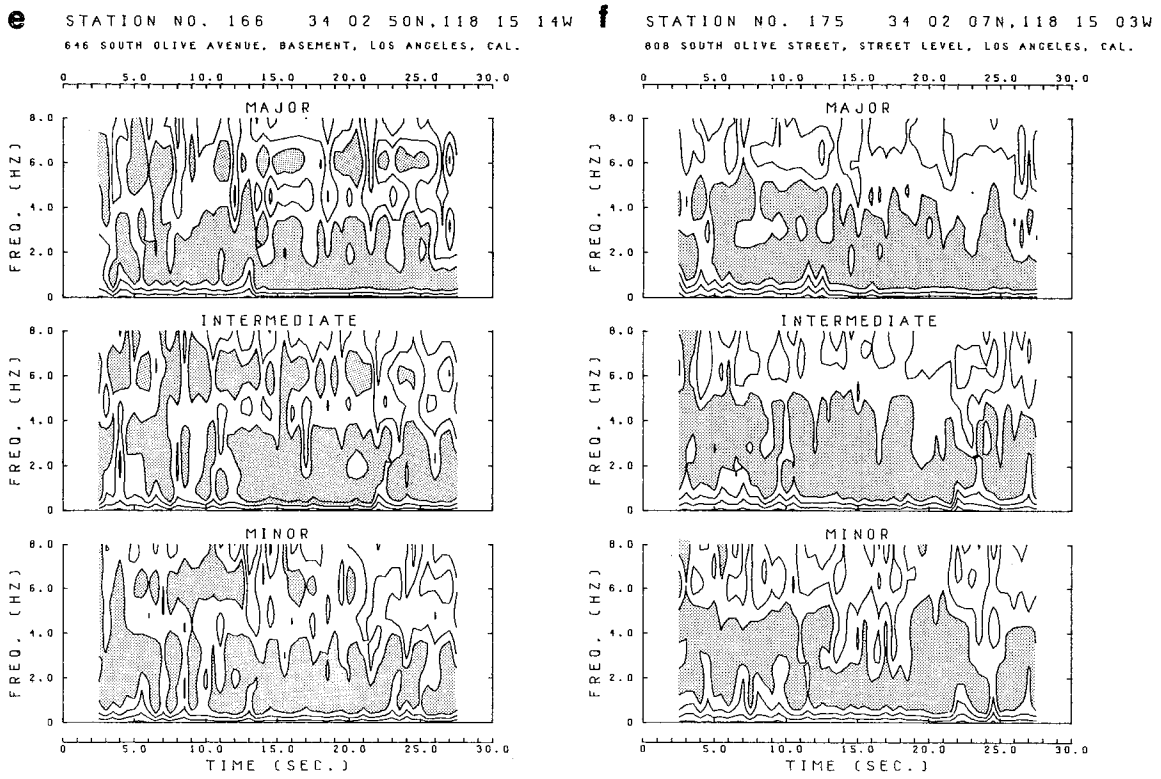


Fig. A.4 (continued)

APPENDIX B

Results of time dependent directions of principal axes and square root of principal variances at stations not included in area groups A through F.

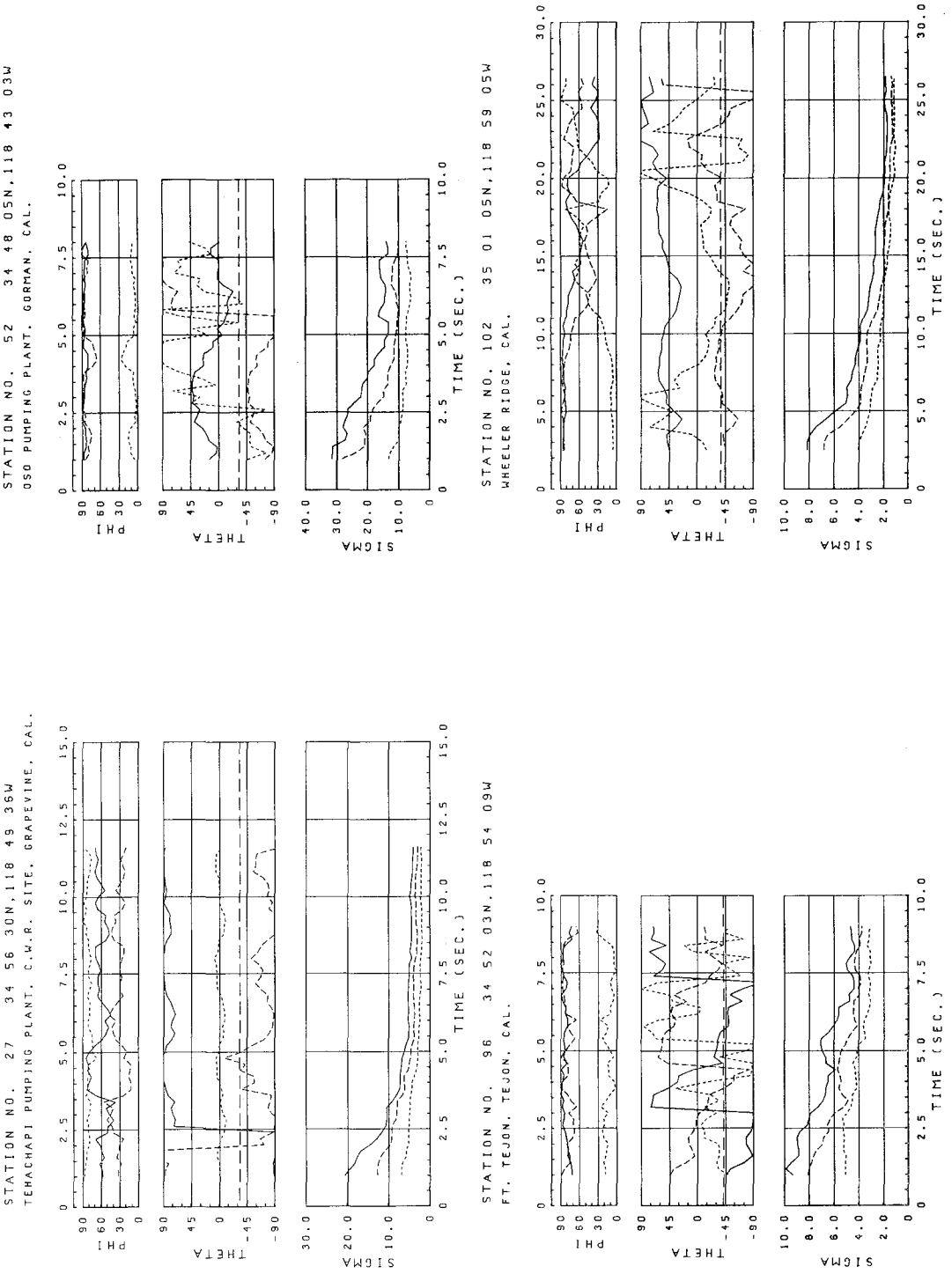


Fig. B.1 Time dependent directions of principal axes and square root of principal variances.

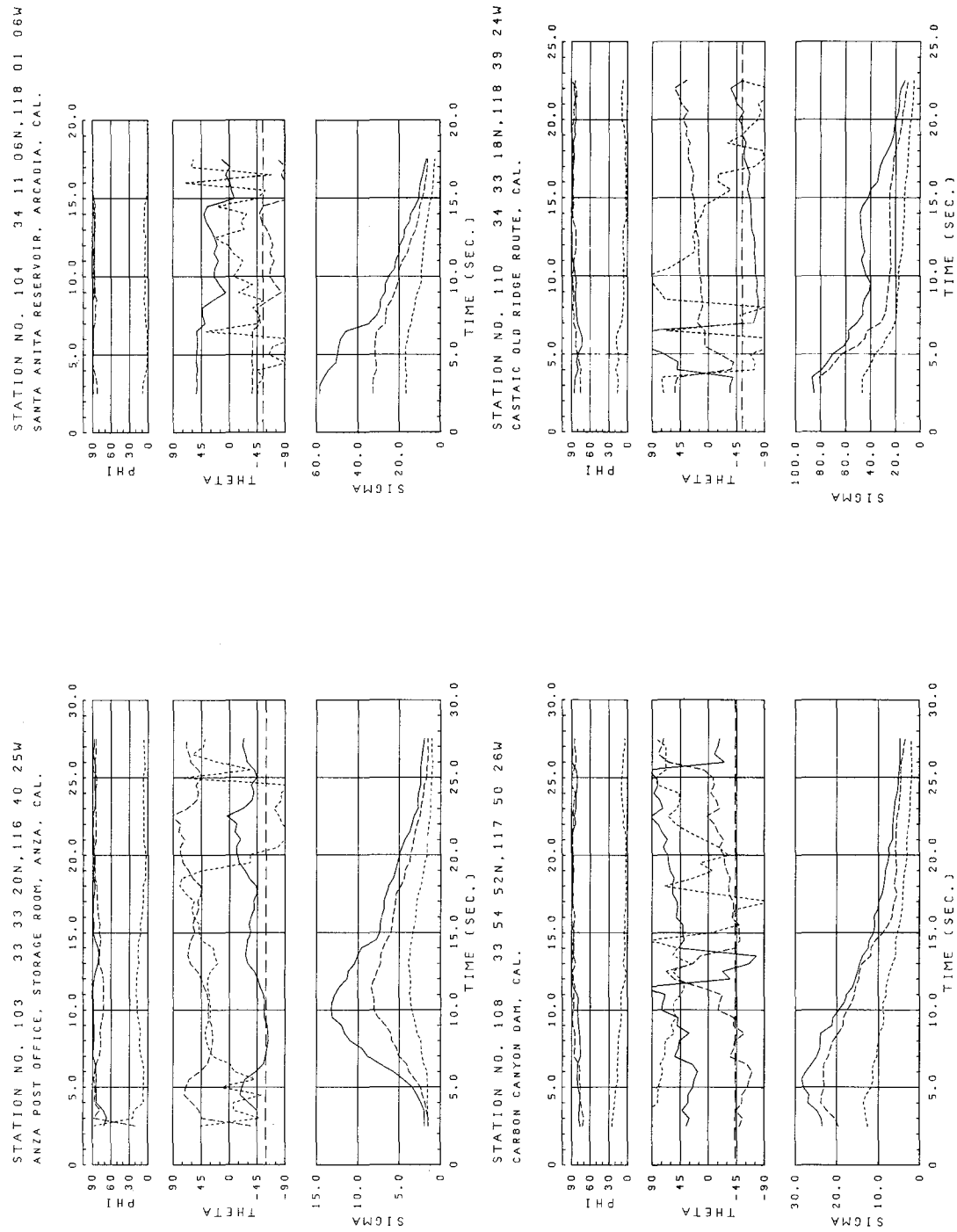


Fig. B.1 (continued)

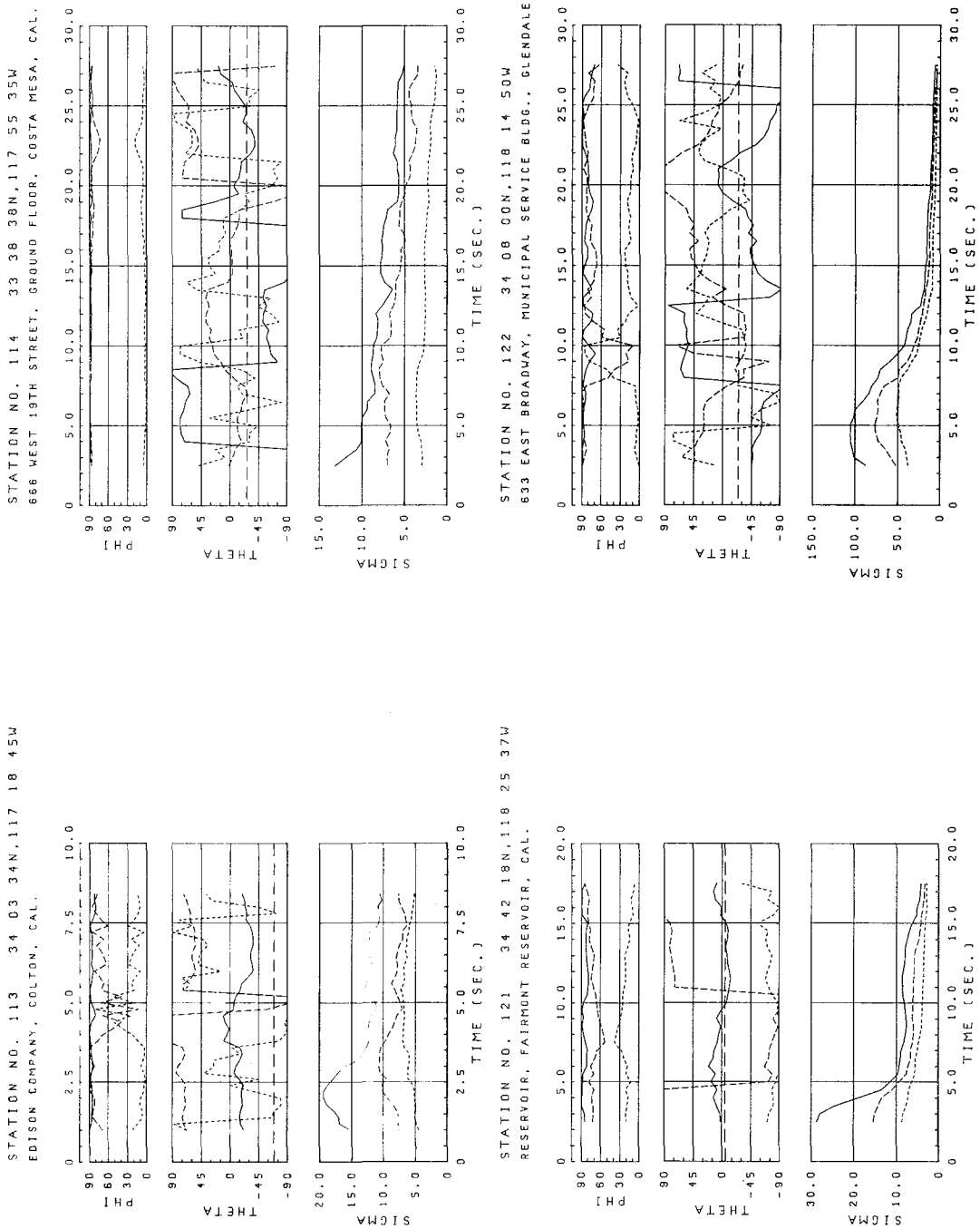


Fig. B.1 (continued)

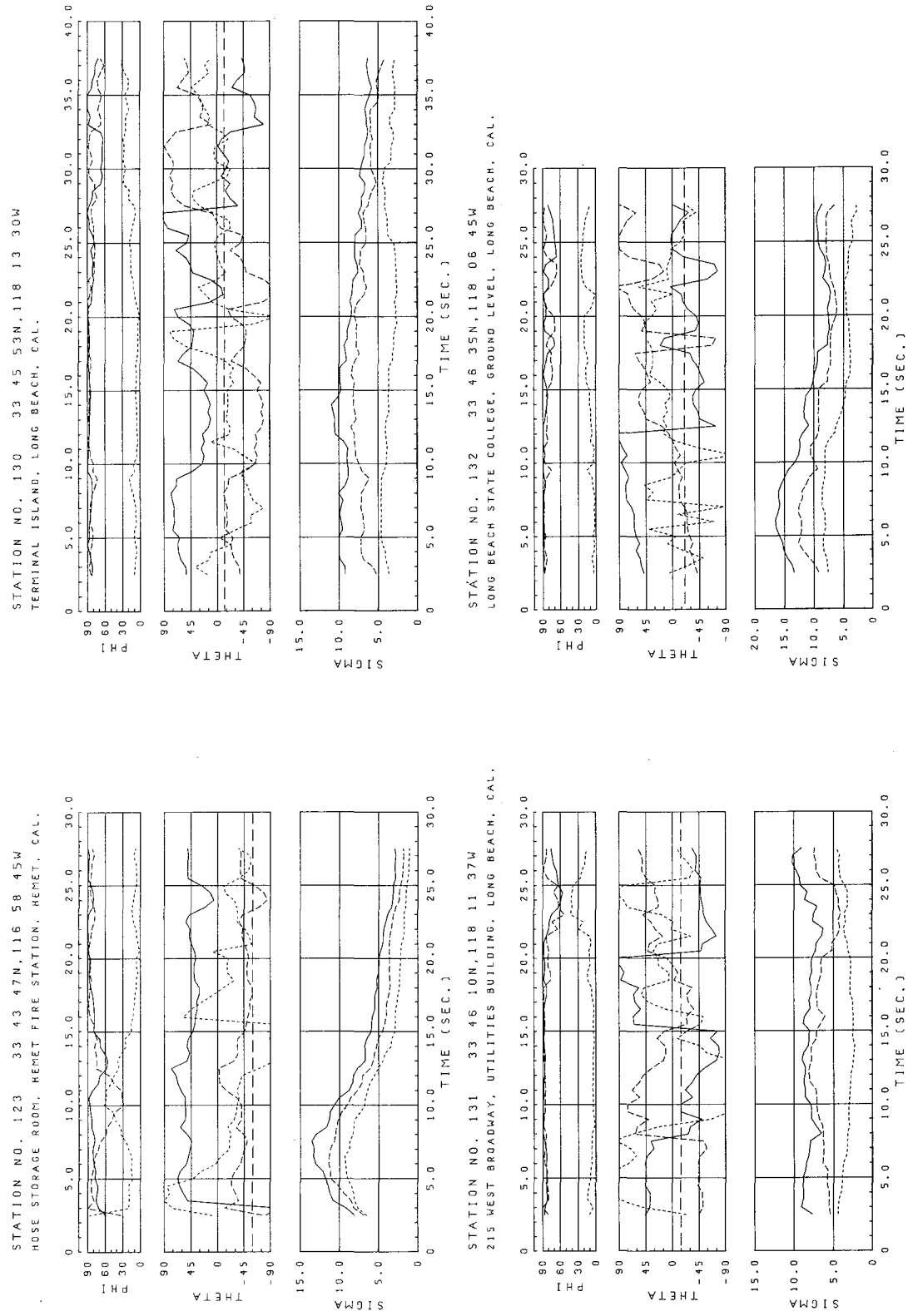


Fig. B.1 (continued)

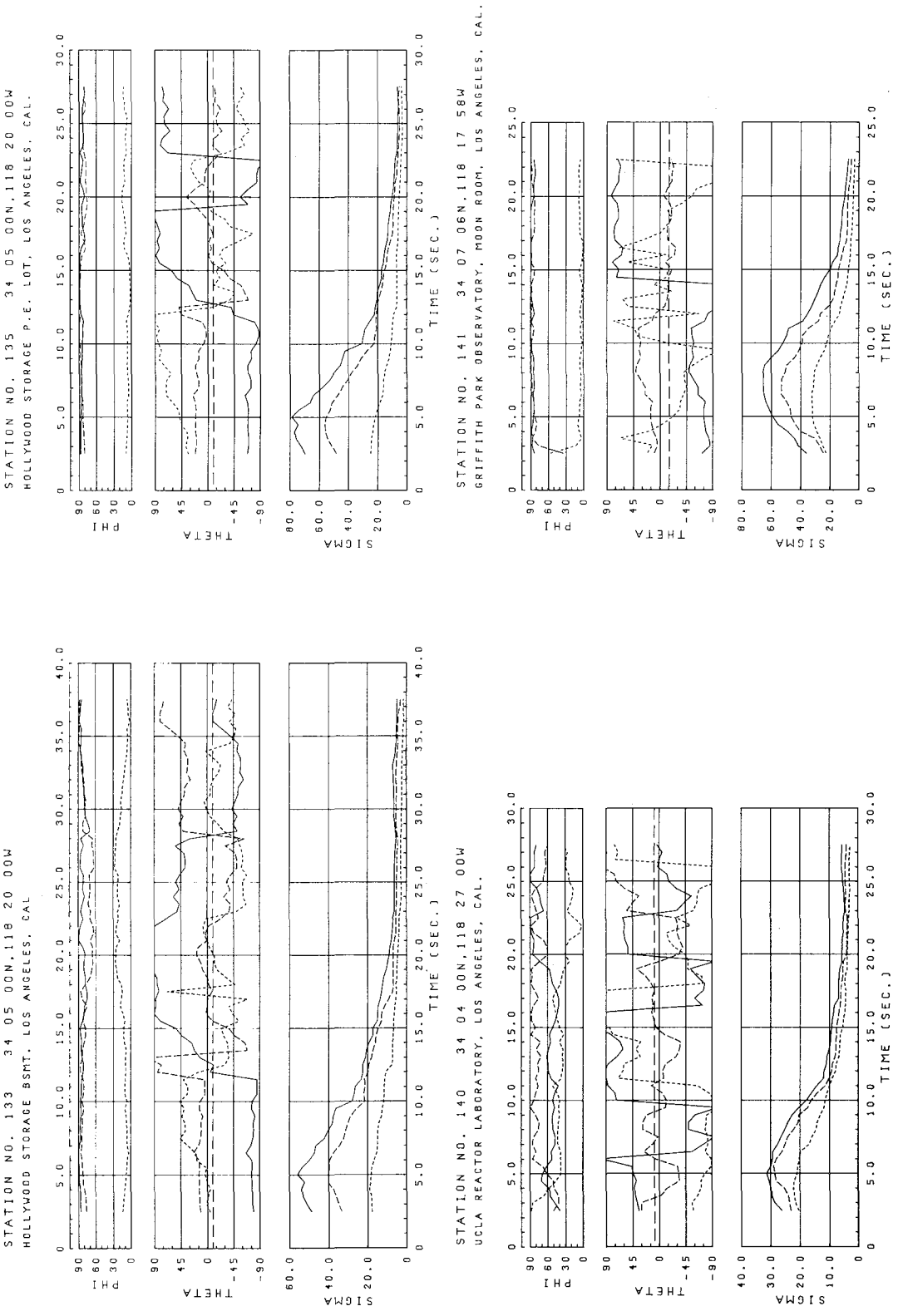


Fig. B.1 (continued)

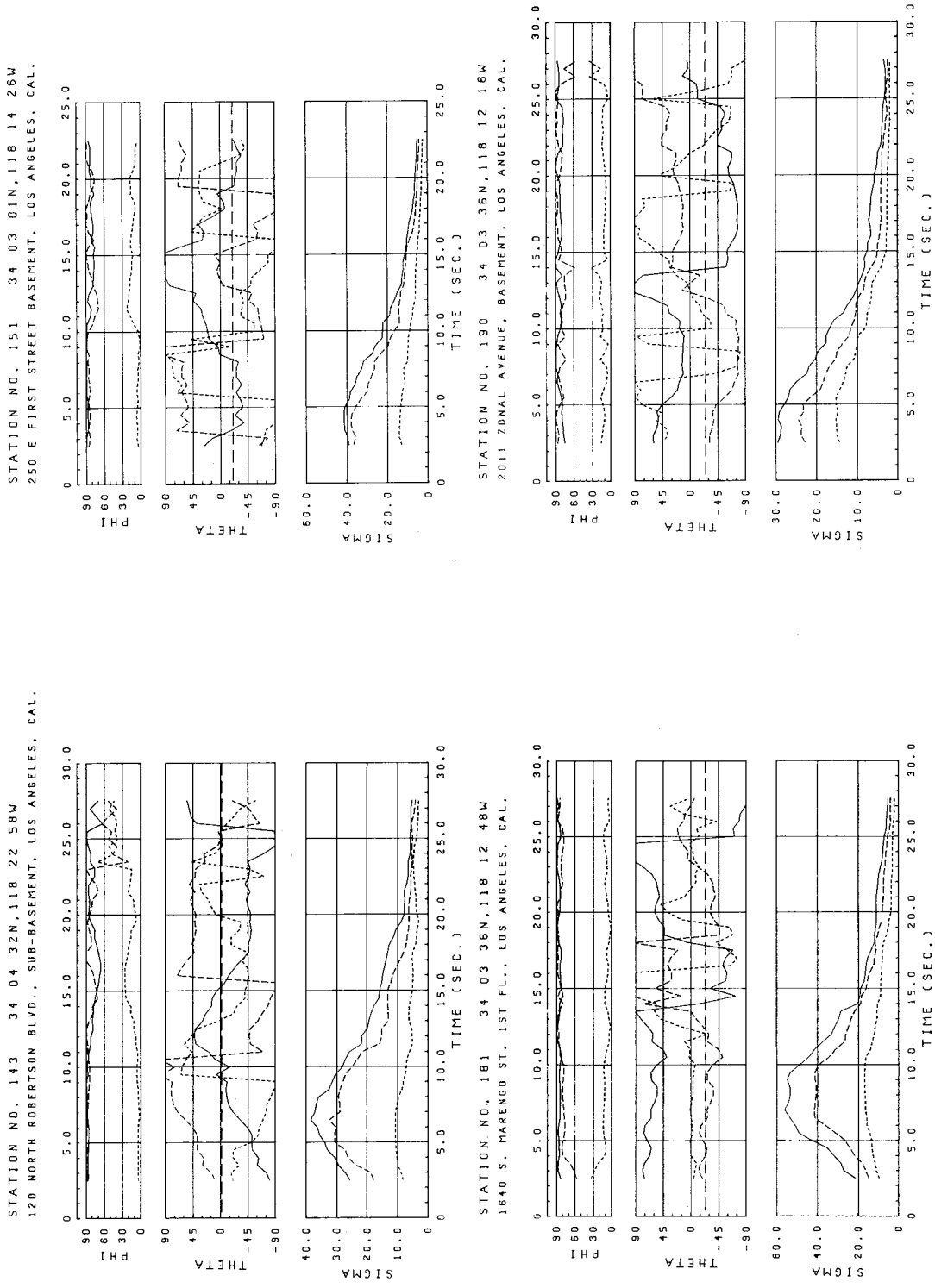


Fig. B.1 (continued)

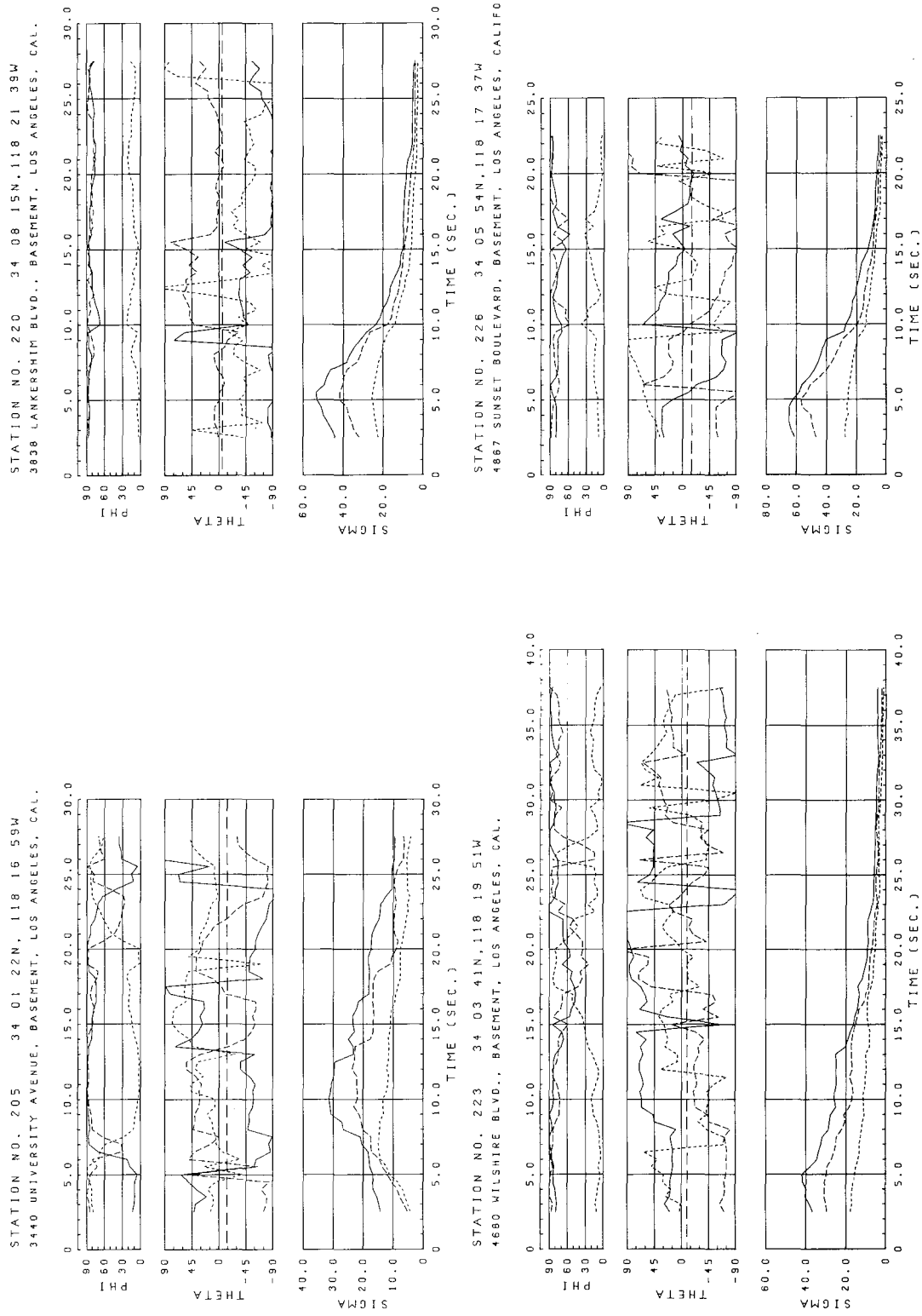


Fig. B.1 (continued)

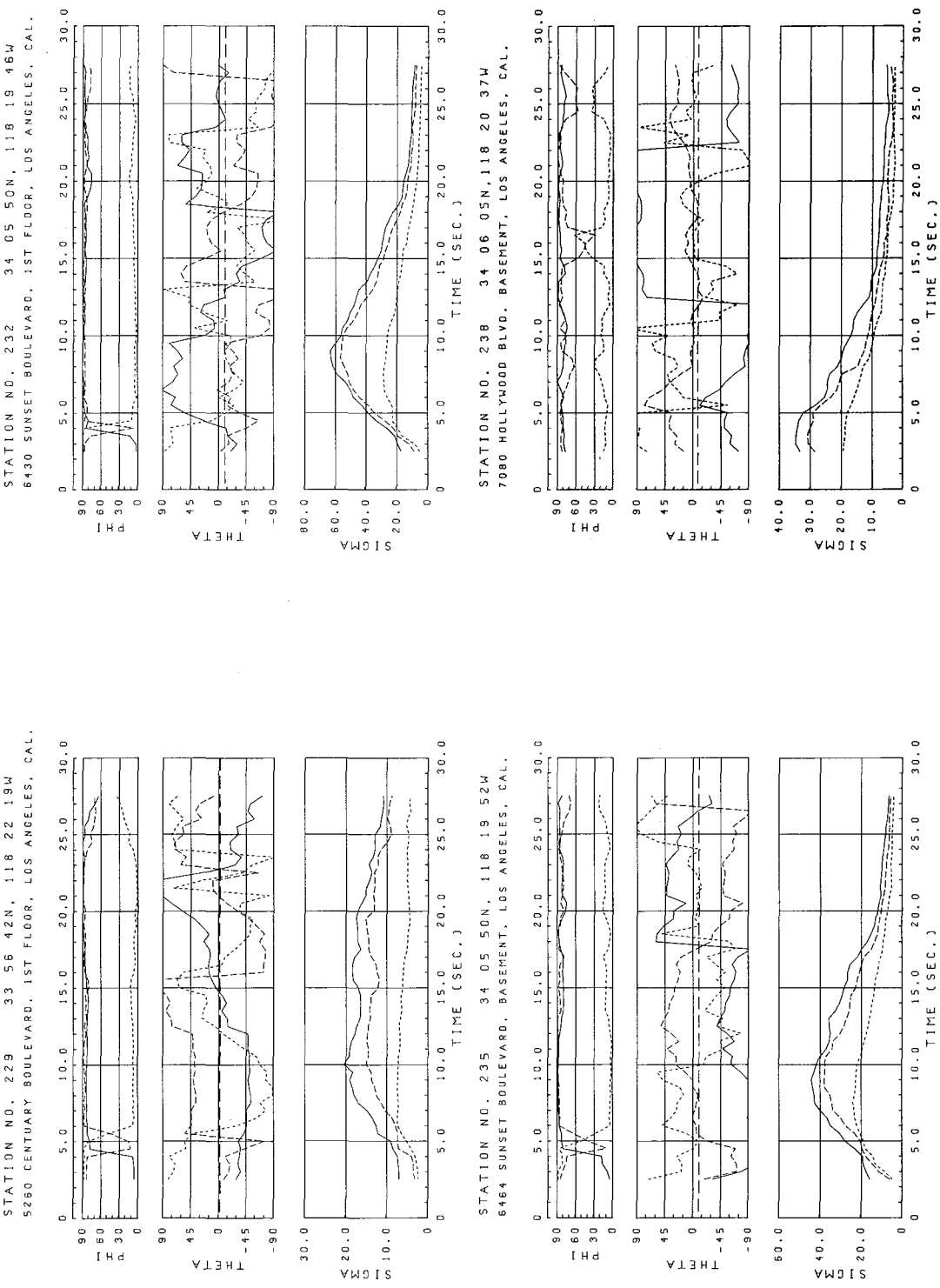
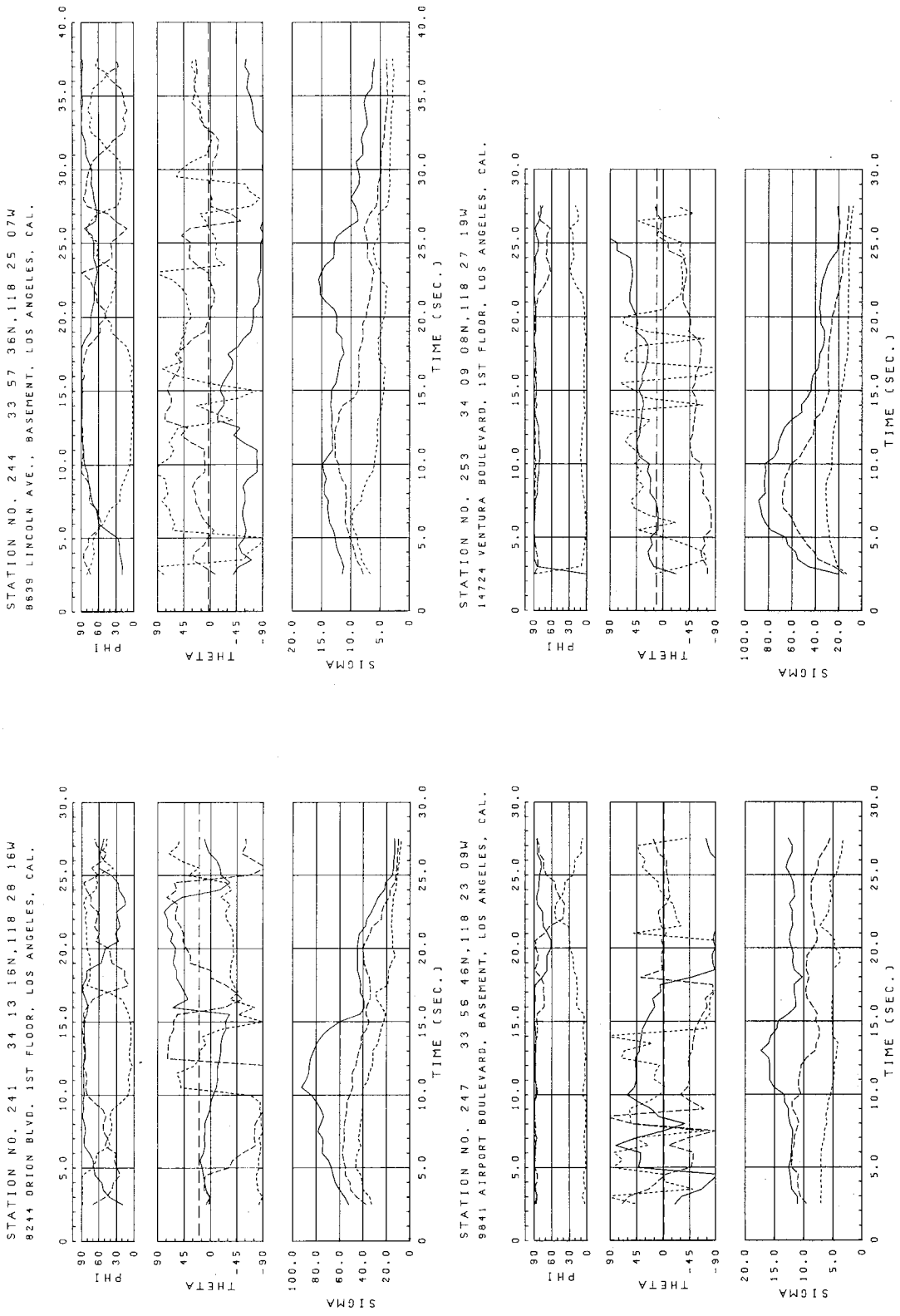


Fig. B.1 (continued)



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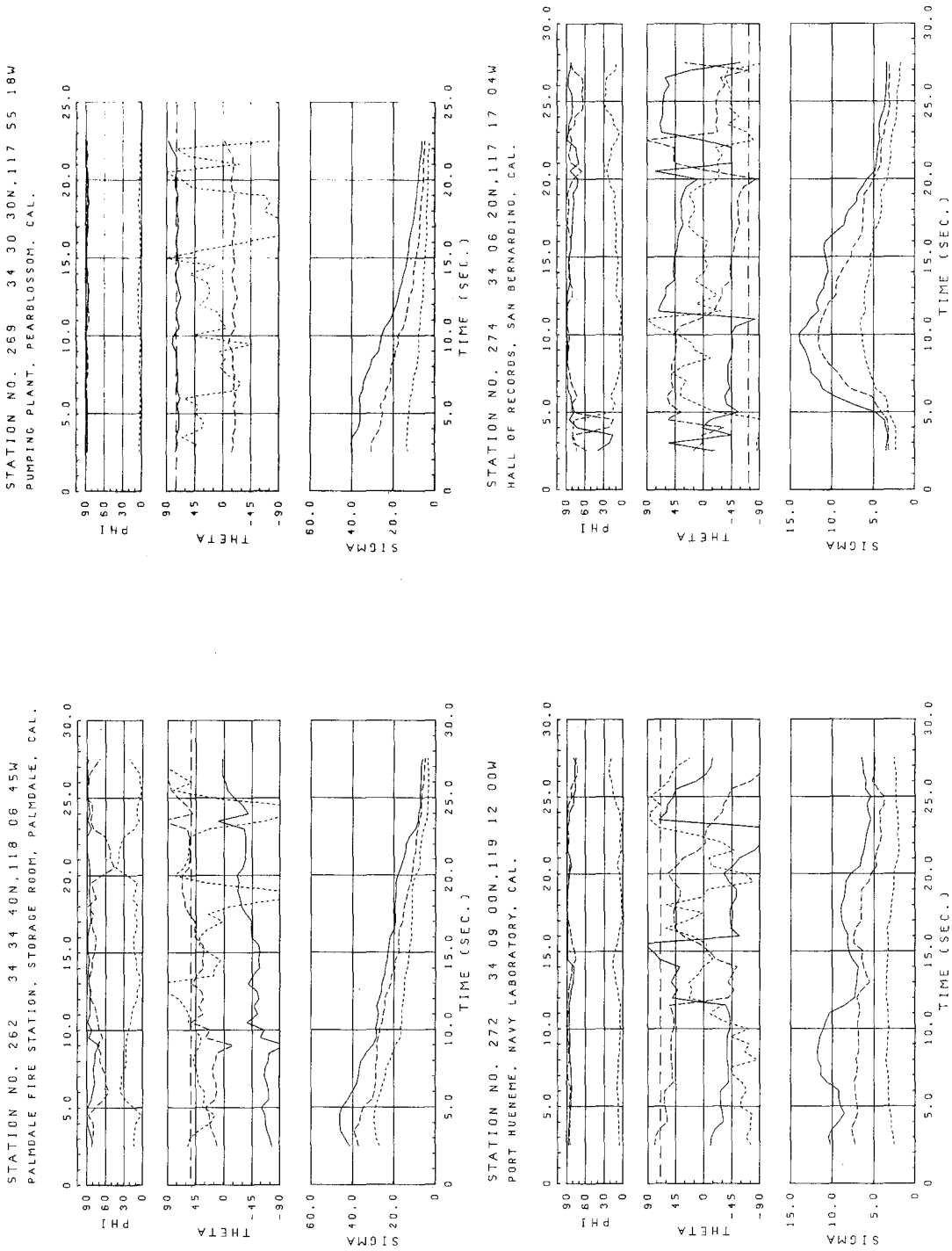


Fig. B.1 (continued)

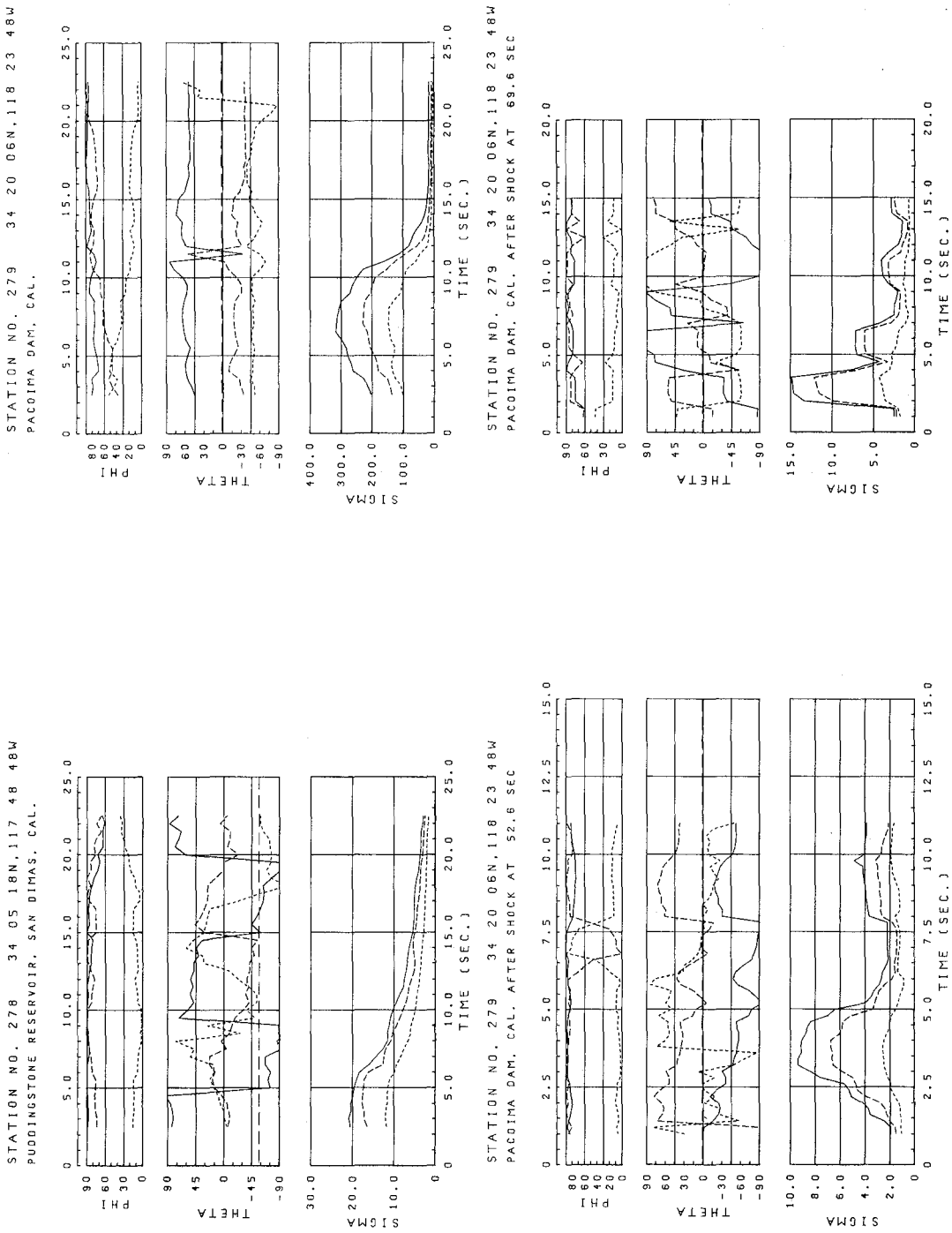
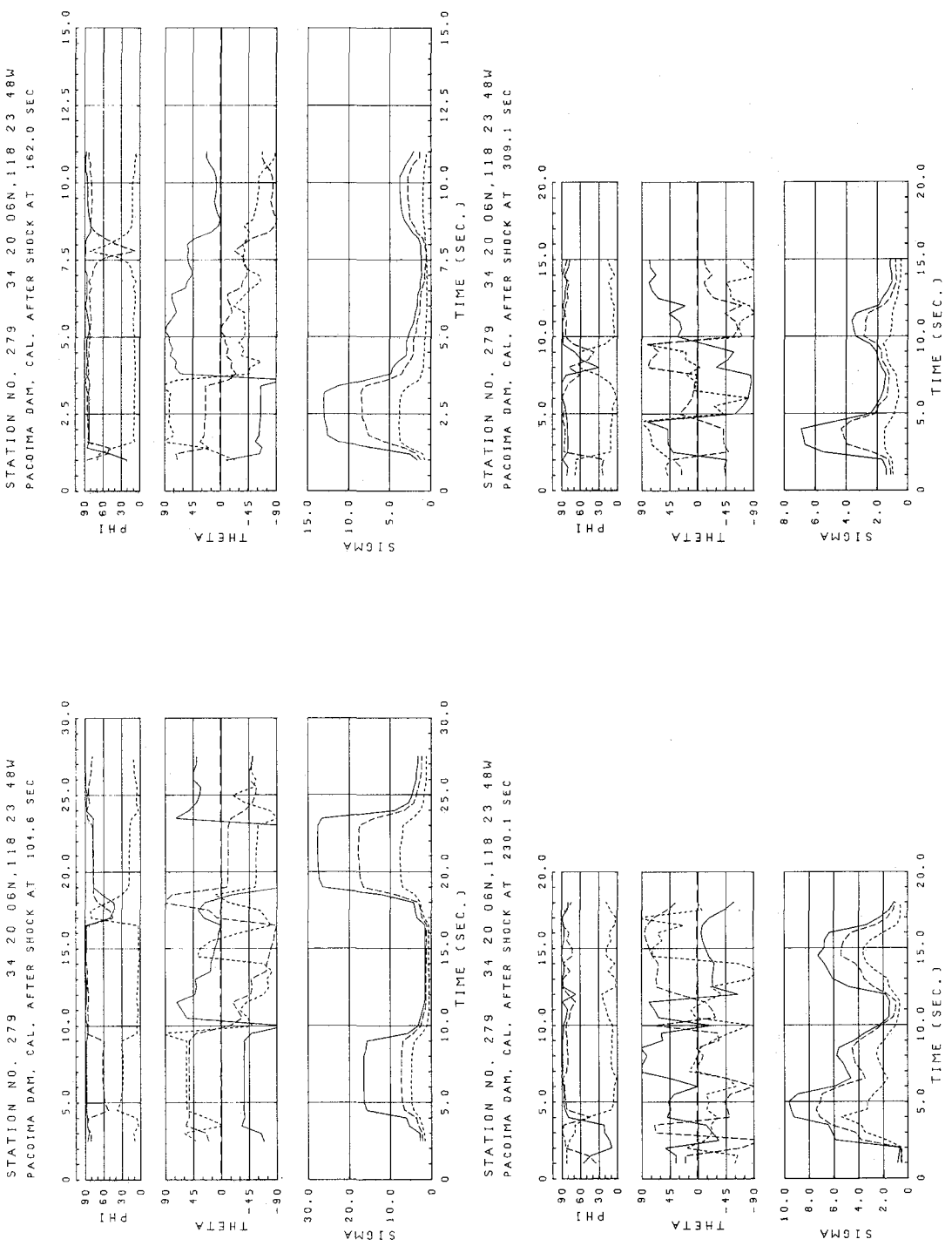


Fig. B.1 (continued)



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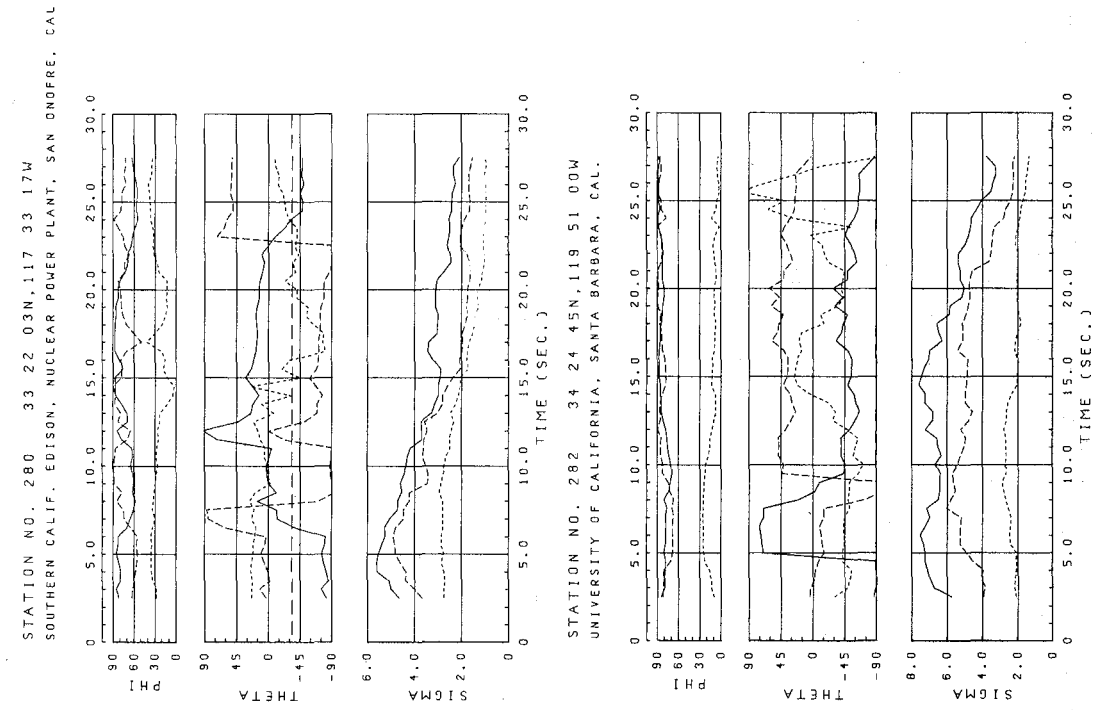

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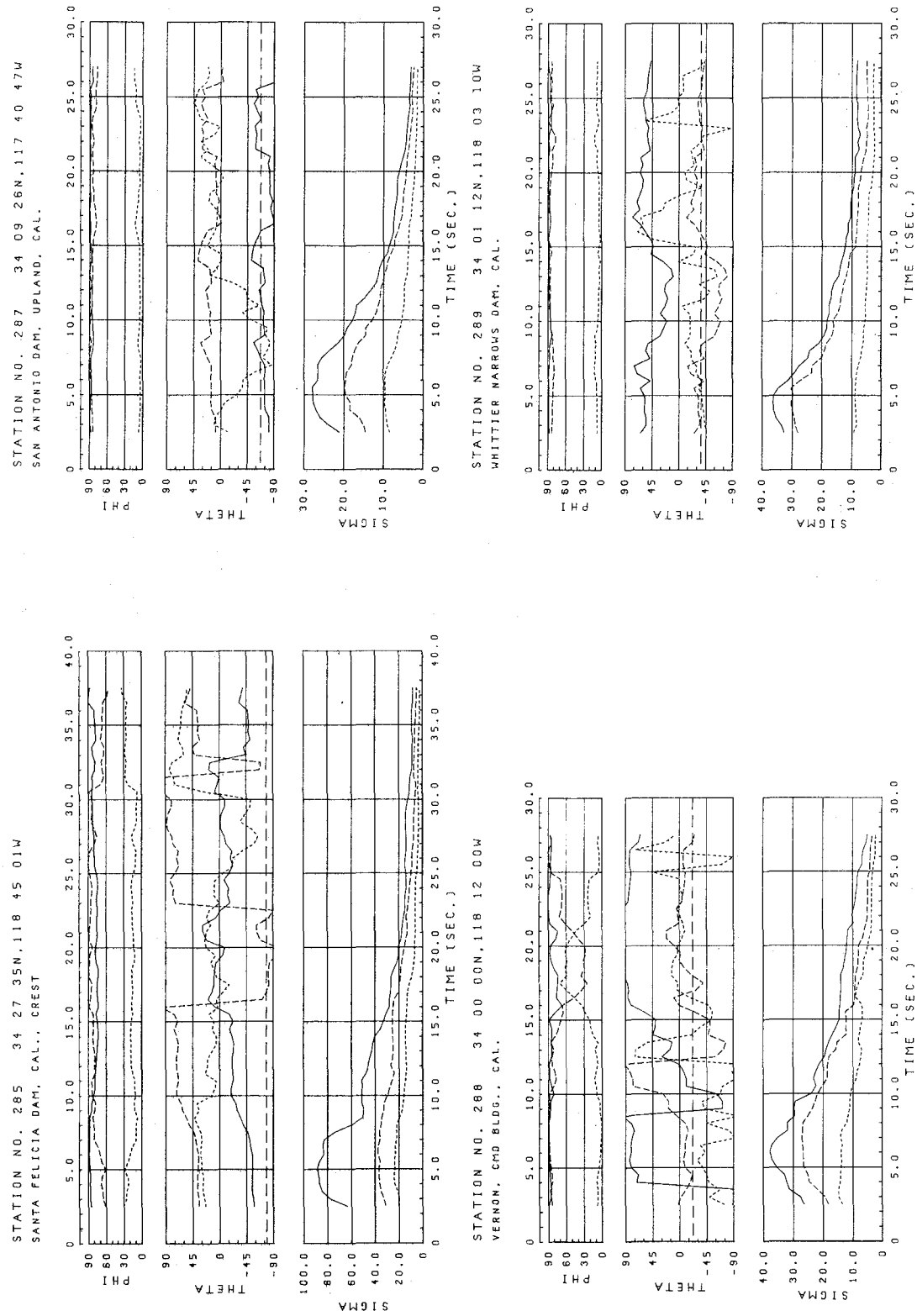
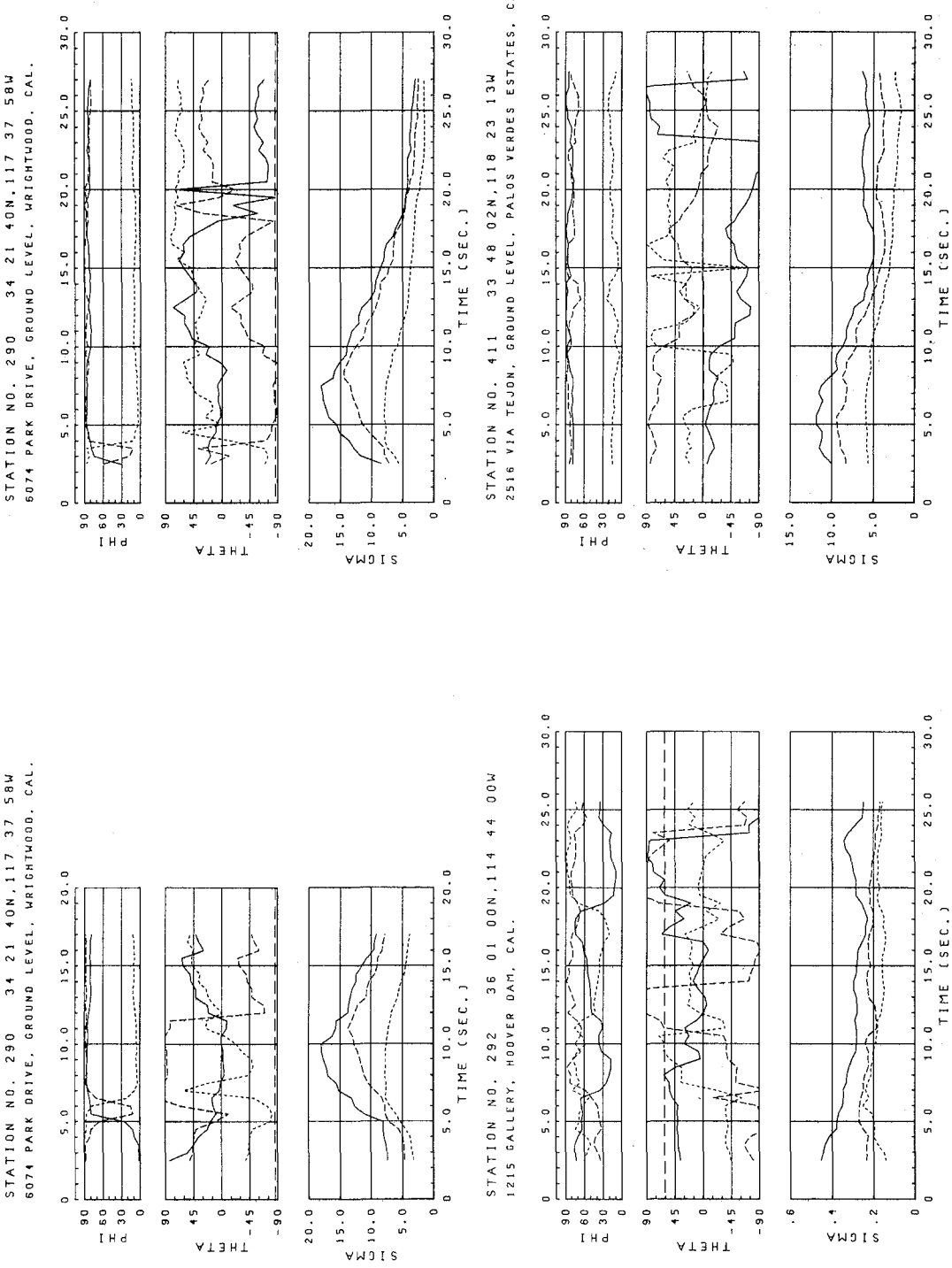


Fig. B.1 (continued)



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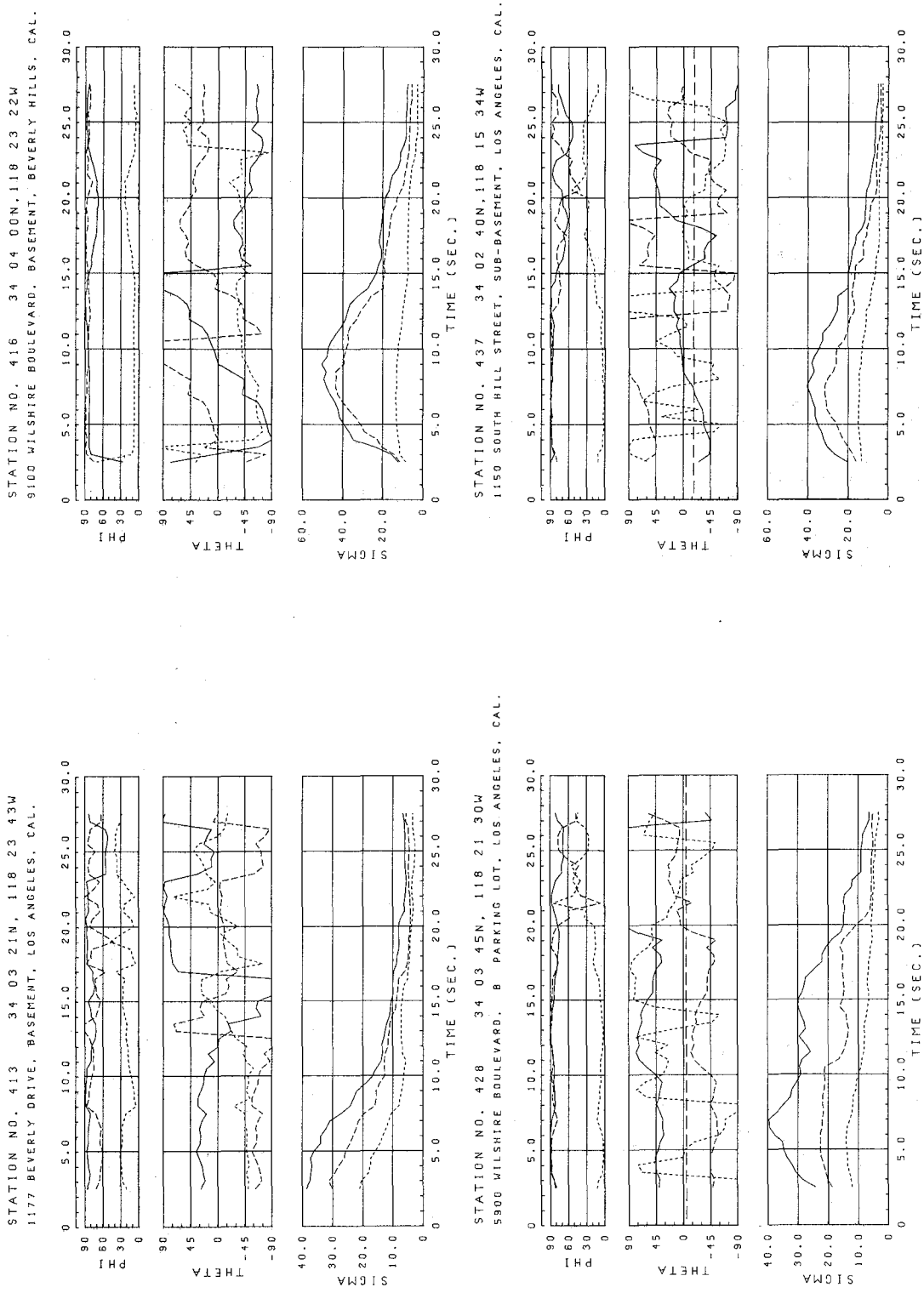


Fig. B.1 (continued)

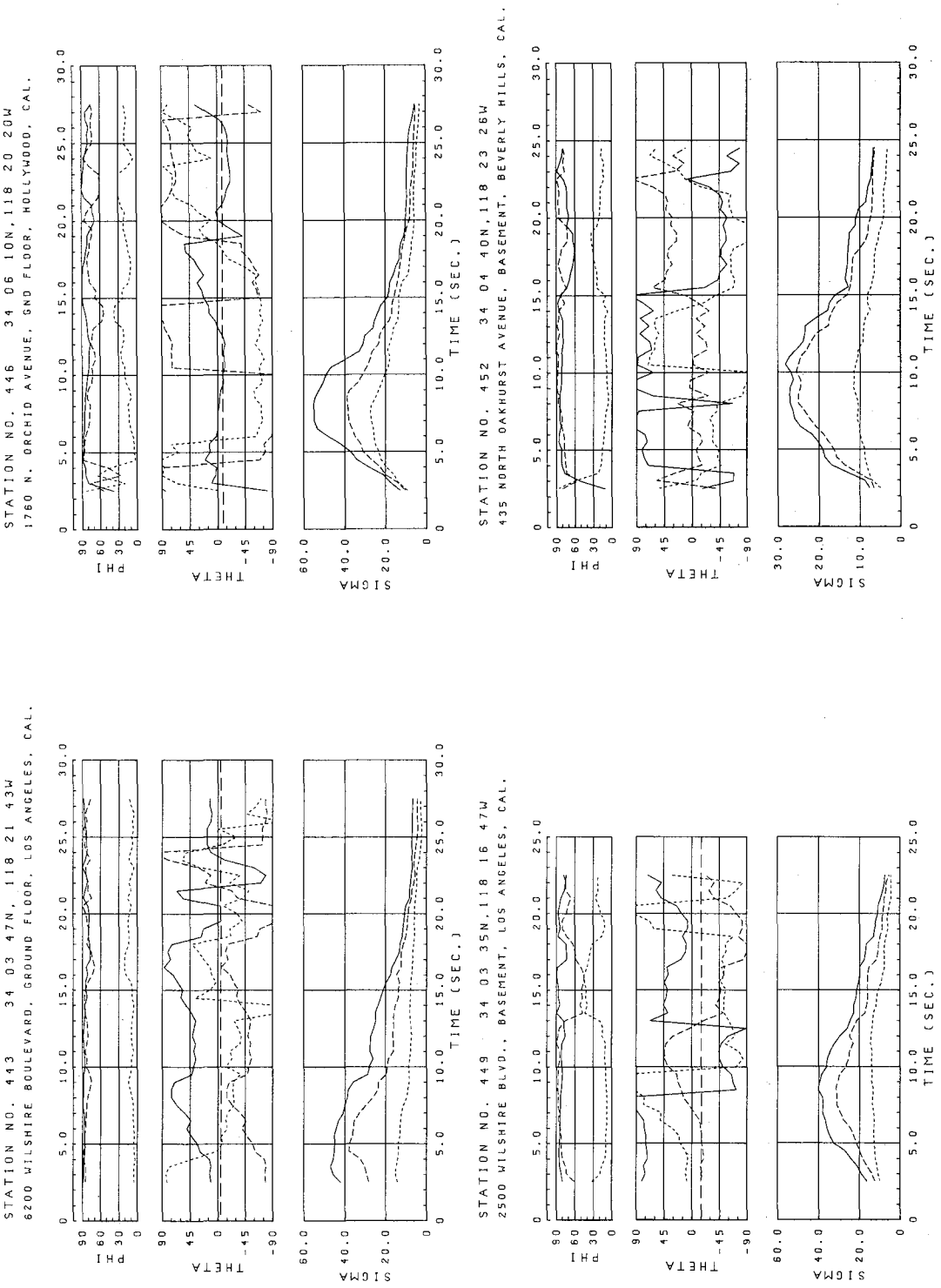


Fig. B.1 (continued)

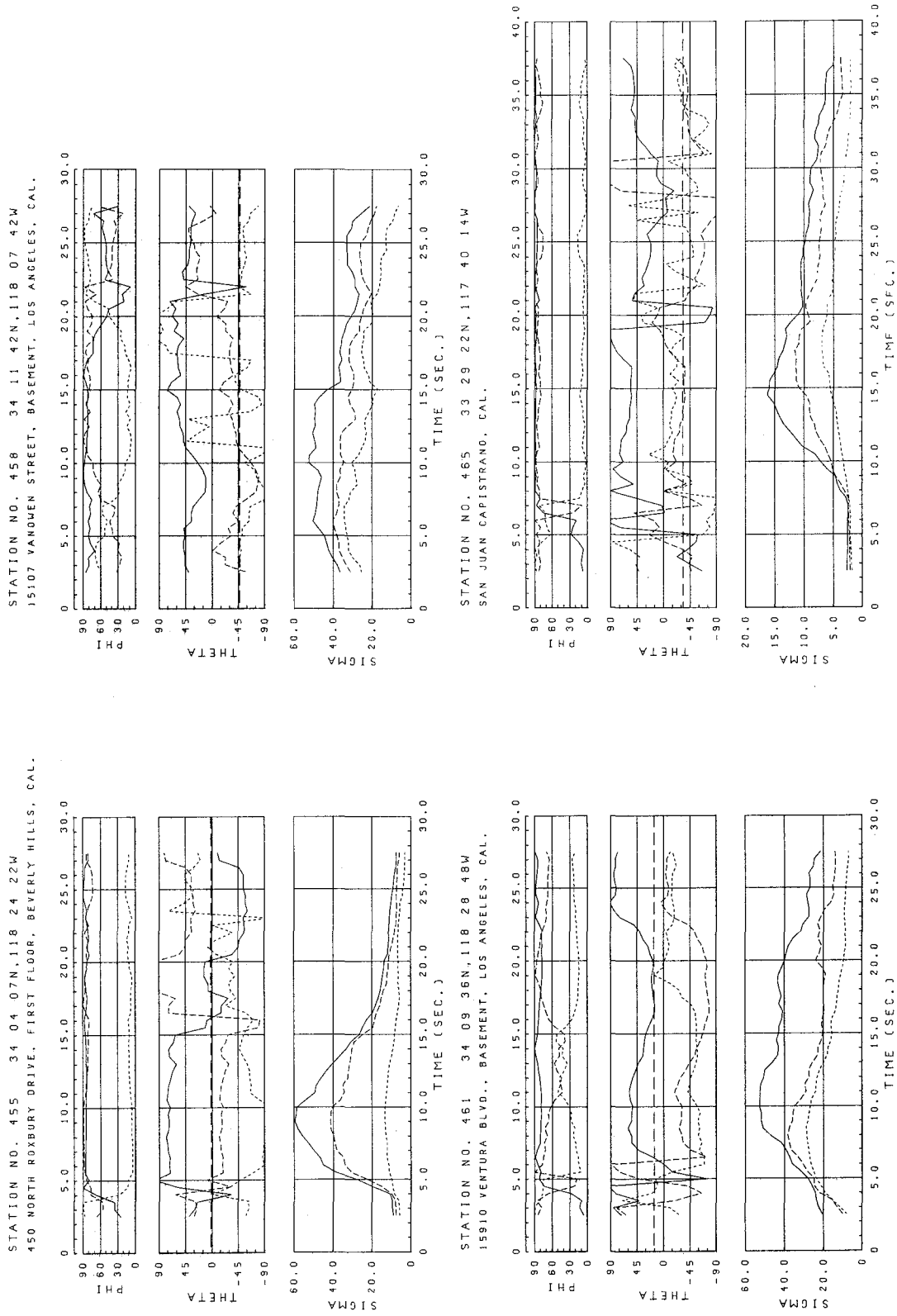
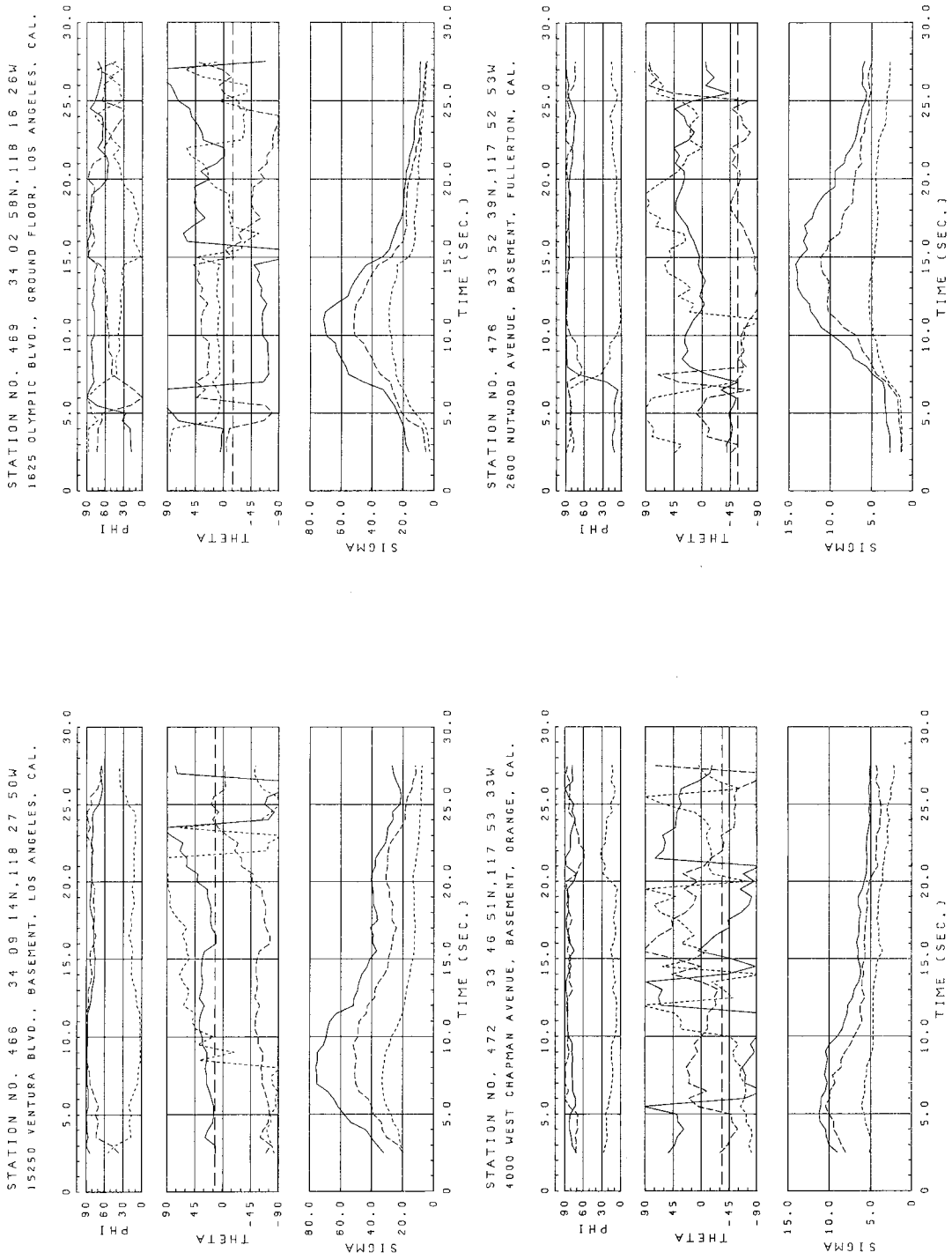


Fig. B.1 (continued)



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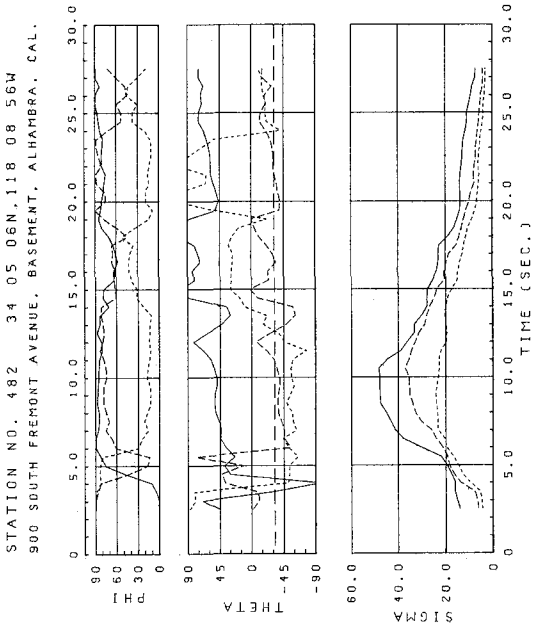

Fig. B.1 (continued)

APPENDIX C

Results of frequency dependent directions of principal axes and square root of principal variances for motions in area groups C, D and E.

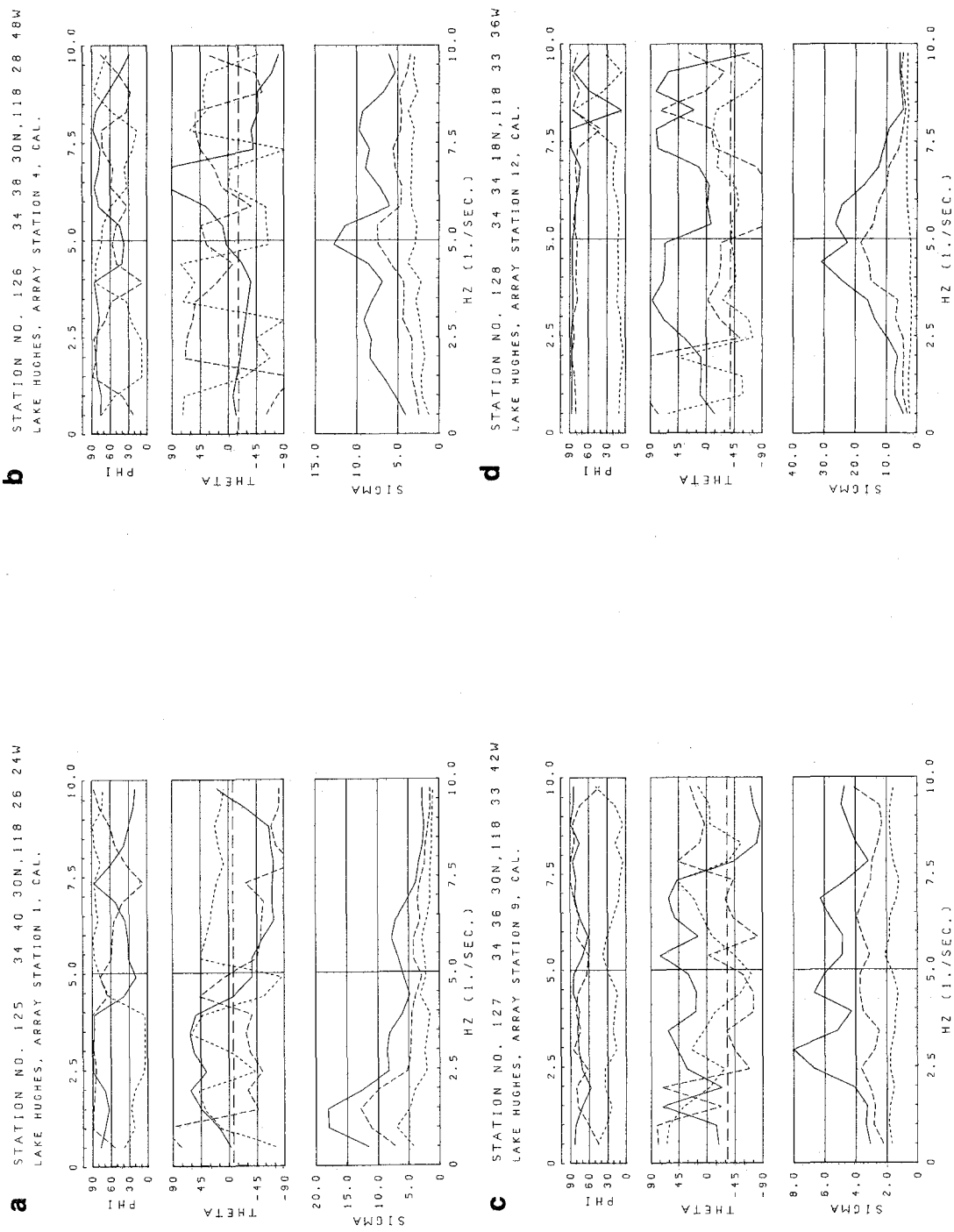

Fig. C.1 Frequency dependent directions of principal axes and square root of principal variances in area C.

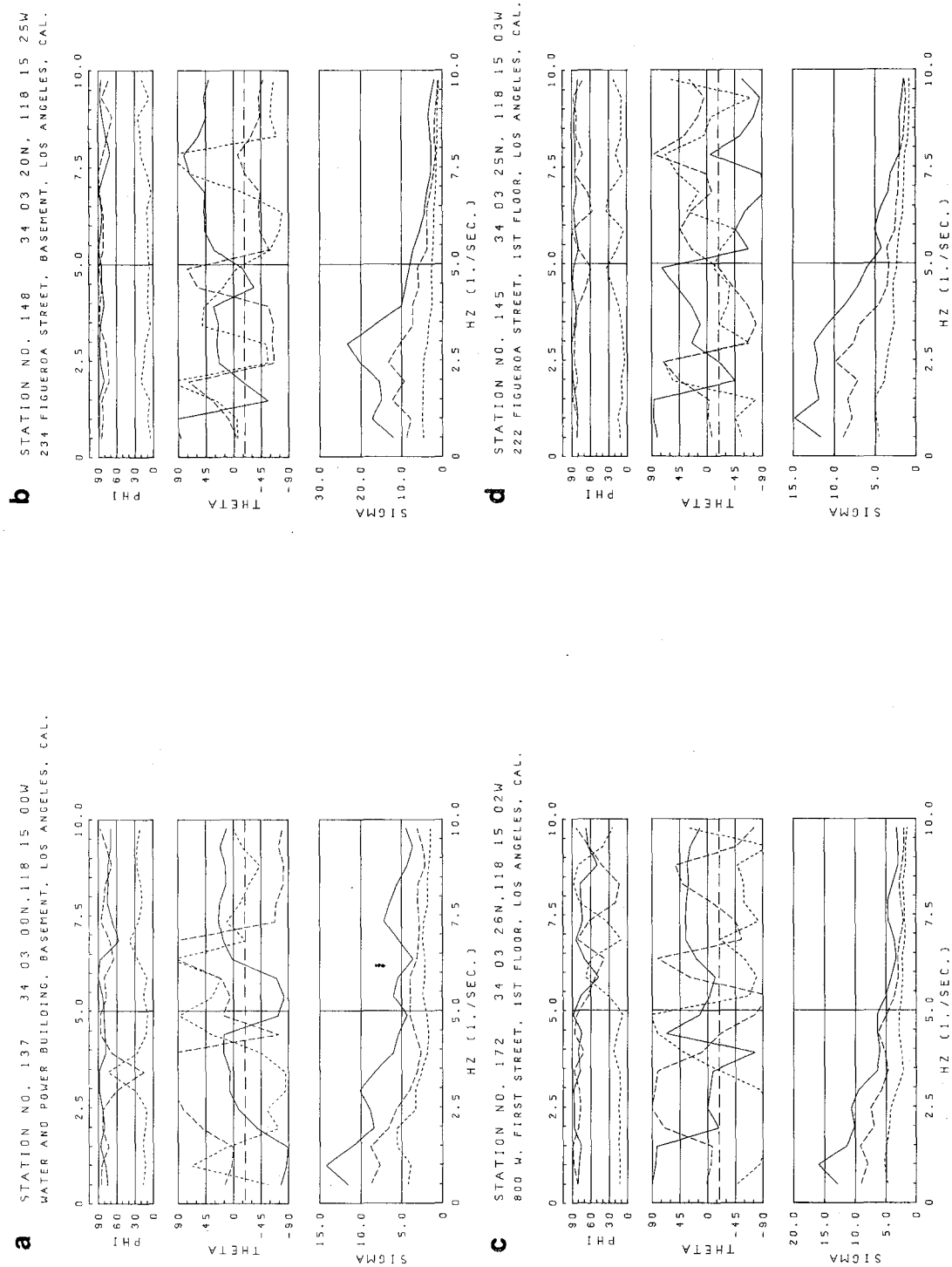

Fig. C.2 Frequency dependent directions of principal axes and square root of principal variances in area D.

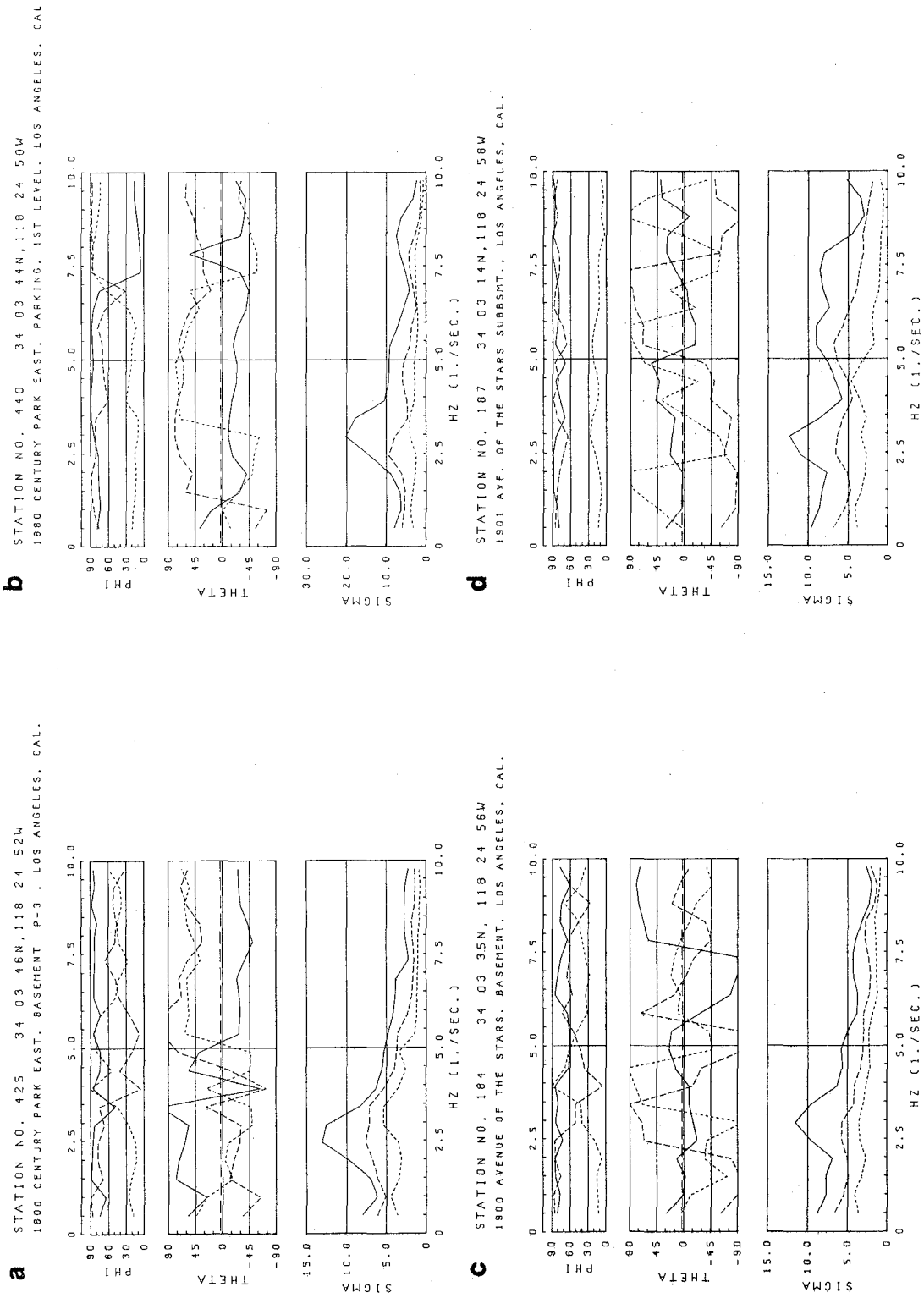

Fig. C.3 Frequency dependent directions of principal axes and square root of principal variances in area E.

APPENDIX D

Results of time dependent principal variances and principal cross correlation coefficients for motions in area groups C, D and E.

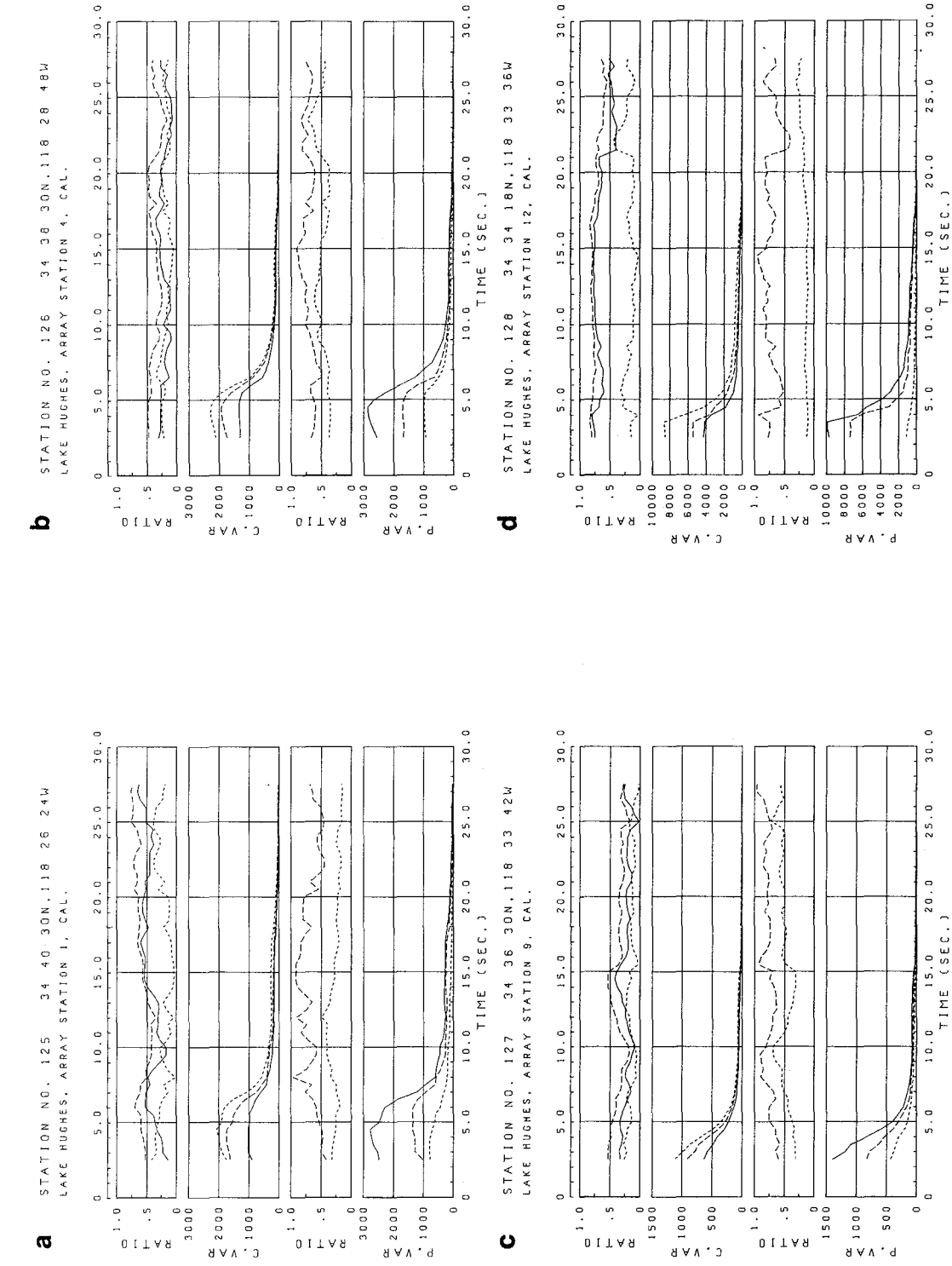

Fig. D.1 Time dependent principal variances and principal cross correlation coefficients in area C.

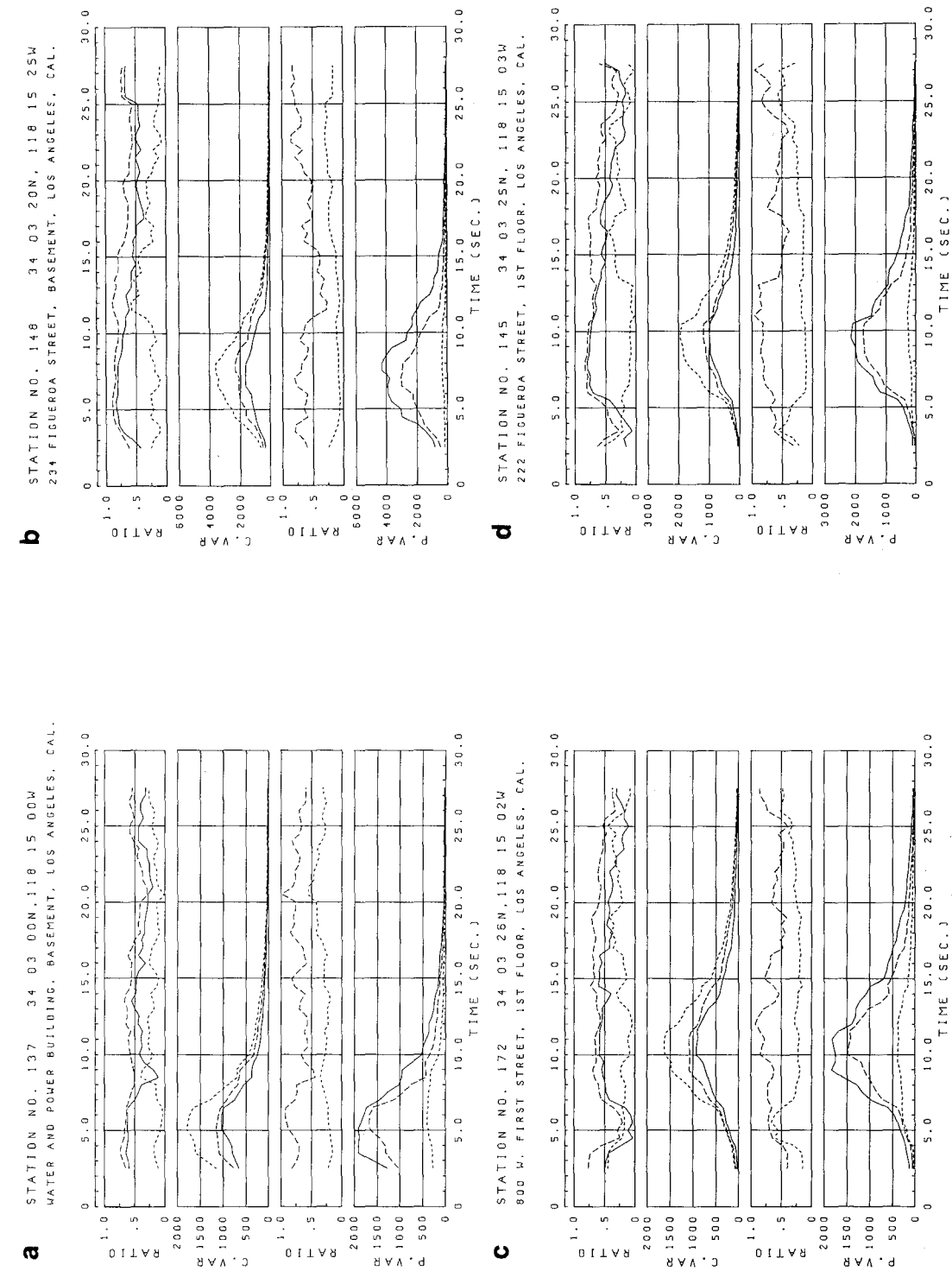

Fig. D.2 Time dependent principal variances and principal cross correlation coefficients in area D.

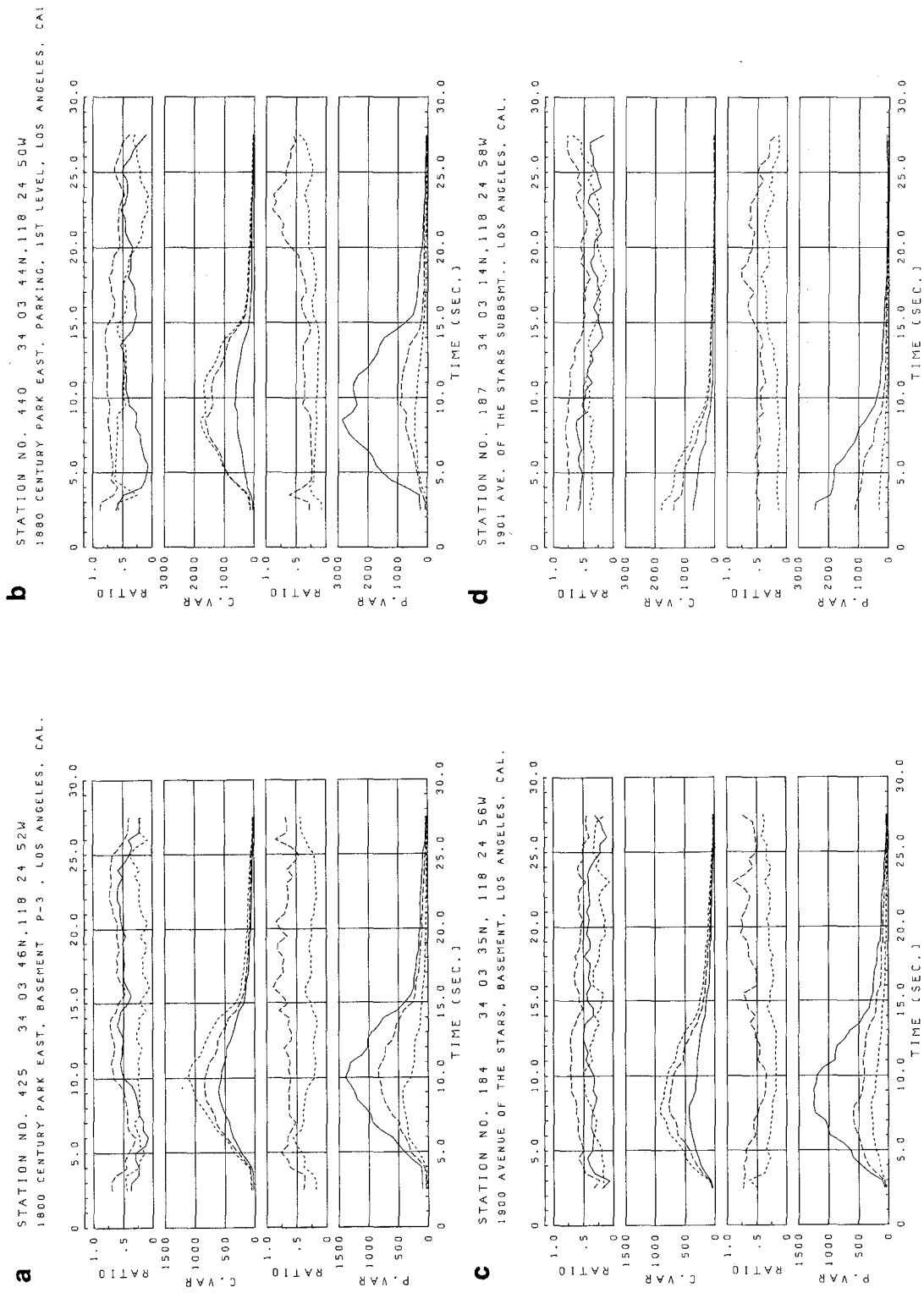

Fig. D.3 Time dependent principal variances and principal cross correlation coefficients in area E.

APPENDIX E

Results of time dependent frequency distribution for motions in area groups C, D and E.

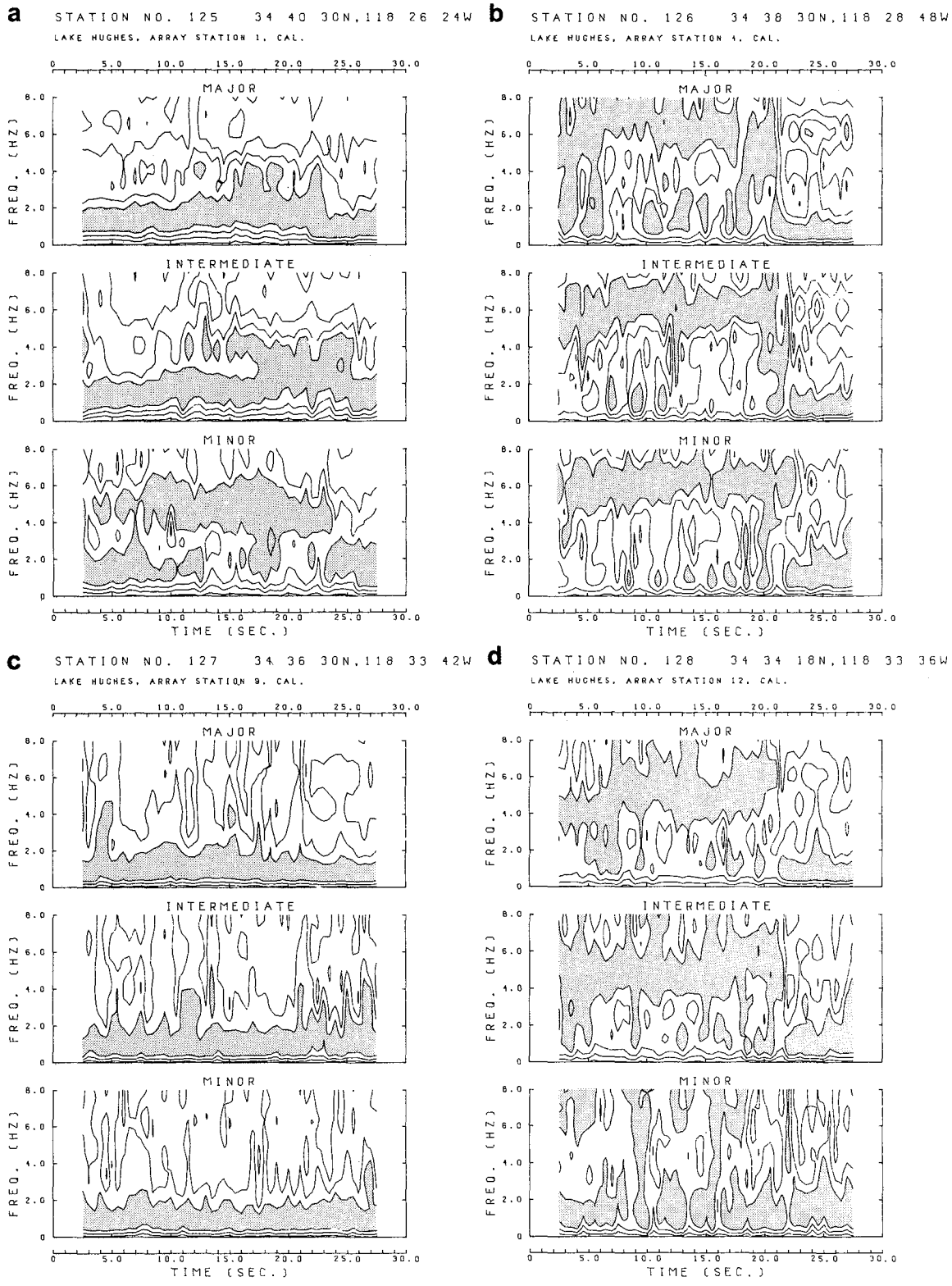

Fig. E.1 Time dependent frequency distribution in area C.

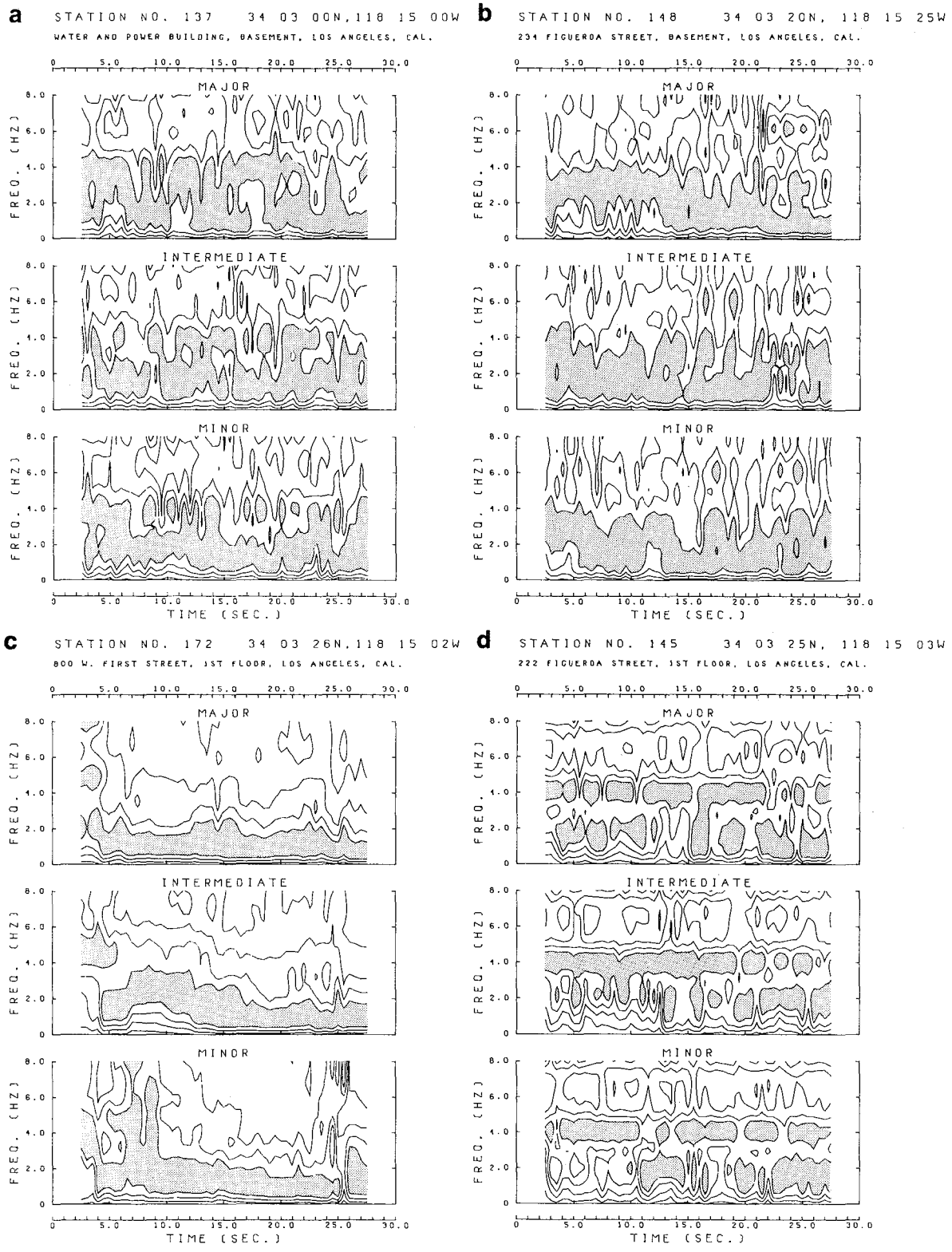

Fig. E.2 Time dependent frequency distribution in area D.

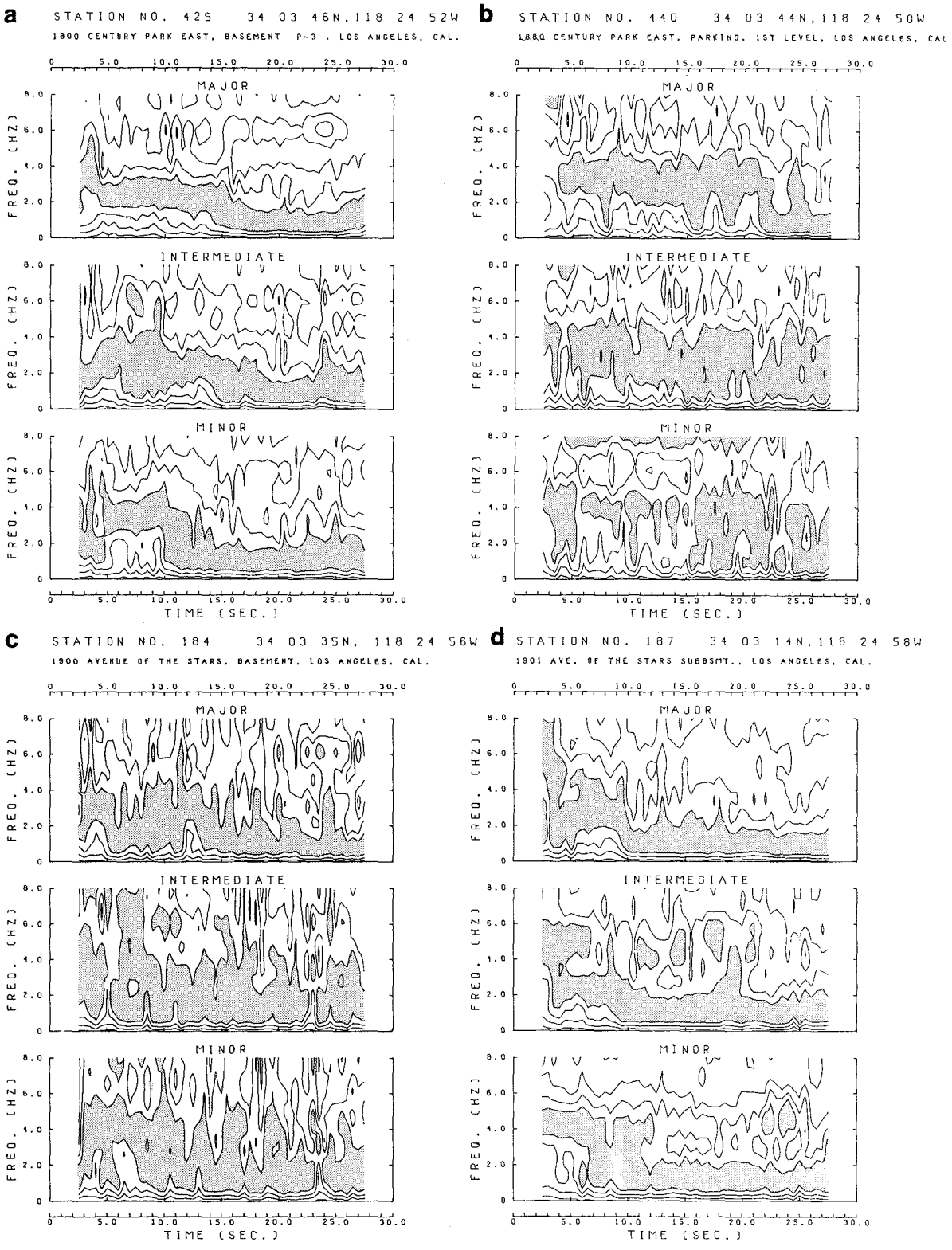

Fig. E.3 Time dependent frequency distribution in area E.

APPENDIX F

Computer program listings.

```
      PROGRAM PGM01  (INPUT,OUTPUT,PUNCH,                                PM01   0
     1                TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=PUNCH,              PM01  10
     2                TAPE1,TAPE99)                                      PM01  20
COMMENT       SUBROUTINES, REQUIRED                                      PM01  30
C   SUBROUTINE DRCTON                                                    PM01  40
C   SUBROUTINE SHB1                                                      PM01  50
C   SUBROUTINE PLTTNG                                                    PM01  60
      DIMENSION CORTIL(200),ICOR(100),FCOR(100)                          PM01  70
      DIMENSION DATA(3,1500)                                             PM01  80
      DIMENSION ACC(3, 250)                                              PM01  90
      DIMENSION G(3,3),E(3),V(3,3),H(3,2),P(3,5)                         PM01 100
      DIMENSION COMP(3),THT(6)                                           PM01 110
      DIMENSION PSHAPE(3, 81),PTHETA(3, 81),PPHI  (3, 81),               PM01 120
     1          PTT   (   81),PYY   (   81),LABEL1(5),LABEL2(7)          PM01 130
      INTEGER CORTIL                                                     PM01 140
      EQUIVALENCE (ACC(   1),CORTIL(1)),(ACC( 201),ICOR(1)),             PM01 150
     1           (ACC( 301),FCOR(1))                                     PM01 160
      CALL SETFXB (1,2500,100)                                           PM01 170
CC                                                                       PM01 180
CC  T1   =  TIME LENGTH OF WINDOW                                        PM01 190
CC  T2   =  TIME, SKIPPED                                                PM01 200
CC  T3   =  TERMINATE LENGTH OF TIME                                     PM01 210
CC                                                                       PM01 220
 1000 READ(5,101) NSKIP,T1,T2,T3,IPR3,IPL3                               PM01 230
      IF(NSKIP.EQ.999) GO TO 9900                                        PM01 240
  101 FORMAT(I8,3F9.0,6I8)                                               PM01 250
  102 FORMAT( 8A10)                                                      PM01 260
  111 FORMAT(10I10)                                                      PM01 270
  113 FORMAT(10F10.1)                                                    PM01 280
      IF(NSKIP.EQ.0) GO TO 1200                                          PM01 290
      NSKIP=3*NSKIP                                                      PM01 300
      CALL SKIPF (5LTAPE1,NSKIP,3HEOF)                                   PM01 310
 1200 WRITE(6,200)                                                       PM01 320
CC     READING MAGNETIC FILESETS                                         PM01 330
      DO 2000 J=1,3                                                      PM01 340
      READ(1,102) CORTIL                                                 PM01 350
      WRITE(6,210) J,(CORTIL(I),I=1,8),(CORTIL(I),I=41,56),              PM01 360
     1             (CORTIL(I),I=169,176)                                 PM01 370
      READ(1,111) ICOR                                                   PM01 380
      COMP(J)=FLOAT(ICOR(27))                                            PM01 390
      KAZU=ICOR(53)                                                      PM01 400
      READ(1,113) FCOR                                                   PM01 410
      IF(KAZU.GT.1500) KAZU=1500                                         PM01 420
      READ(1,113) (DATA(J,I),I=1,KAZU)                                   PM01 430
      CALL SKIPF (5LTAPE1,    1,3HEOF)                                   PM01 440
 2000 CONTINUE                                                           PM01 450
      DO 2100 I=1,4                                                      PM01 460
 2100 LABEL1(I)=CORTIL(I+40)                                             PM01 470
      DO 2110 I=1,6                                                      PM01 480
 2110 LABEL2(I)=CORTIL(I+48)                                             PM01 490
CC     PRINT OUT INFORMATIONS OF EPICENTER AND STATION                   PM01 500
      WRITE(6,220 ) (ICOR(I),I=16,21)                                    PM01 510
      WRITE(6,230 ) (ICOR(I),I=10,15)                                    PM01 520
      EPLAT=FLOAT(    ICOR(16) )+FLOAT(ICOR(17))/60.                     PM01 530
     1                          +FLOAT(ICOR(18))/3600.                  PM01 540
      EPLON=ABS(FLOAT(ICOR(19)))+FLOAT(ICOR(20))/60.                     PM01 550
     1                          +FLOAT(ICOR(21))/3600.                  PM01 560
      OBLAT=FLOAT(    ICOR(10) )+FLOAT(ICOR(11))/60.                     PM01 570
     1                          +FLOAT(ICOR(12))/3600.                  PM01 580
      OBLON=ABS(FLOAT(ICOR(13)))+FLOAT(ICOR(14))/60.                     PM01 590
     1                          +FLOAT(ICOR(15))/3600.                  PM01 600
CC                                                                       PM01 610
  200 FORMAT(1H1)                                                        PM01 620
  210 FORMAT(1H0      ,13HRECORD NO. = ,I2,   /1H ,5X,8A10,              PM01 630
     1           /1H , 5X,8A10,/1H , 5X,8A10,/1H , 5X,8A10)             PM01 640
  220 FORMAT(/1H0,10X,12HEPICENTER = ,3I4,8H N (LAT),                    PM01 650
     1        /1H ,22X,                 3I4,8H W (LON))                 PM01 660
  230 FORMAT(/1H ,10X,12HSTATION   = ,3I4,8H N (LAT),                    PM01 670
     1        /1H ,22X,                 3I4,8H W (LON))                 PM01 680
CC                                                                       PM01 690
      CALL DRCTON  (OBLAT,OBLON,EPLAT,EPLON,THETA)                       PM01 700
      WRITE(6,3050) T1,T2,T3                                             PM01 710
 3050 FORMAT(/1H0,25HTIME LENGTH OF WINDOW  = ,F15.7,7H (SEC.),          PM01 720
     1        /1H ,25HTIME INTERVAL, SKIPPED = ,F15.7,7H (SEC.),        PM01 730
     2        /1H ,25HTERMINATE LENGTH       = ,F15.7,7H (SEC.))       PM01 740
CC     COMPUTE AVERAGE VALUES                                            PM01 750
      N1=          1.001                                                 PM01 760
      N2=T2   /.02+ .001                                                 PM01 770
      SUM1=0.                                                            PM01 780
      SUM2=0.                                                            PM01 790
      SUM3=0.                                                            PM01 800
      DO 3100 I=N1,N2                                                    PM01 810
      SUM1=SUM1+DATA(1,I)                                                PM01 820
      SUM2=SUM2+DATA(2,I)                                                PM01 830
 3100 SUM3=SUM3+DATA(3,I)                                                PM01 840
      XX=1./FLOAT(N2-N1+1)                                               PM01 850
      AVE1=SUM1*XX                                                       PM01 860
      AVE2=SUM2*XX                                                       PM01 870
      AVE3=SUM3*XX                                                       PM01 880
      WRITE(6,3150) AVE1,AVE2,AVE3                                       PM01 890
 3150 FORMAT(1H0,20X,30HAVERAGE VALUE OF ACCELEROGRAMS,                  PM01 900
     1       /1H ,20X,3E15.7,/)                                          PM01 910
      DO 3200 I=N1,N2                                                    PM01 920
      DATA(1,I)=DATA(1,I)-AVE1                                           PM01 930
      DATA(2,I)=DATA(2,I)-AVE2                                           PM01 940
 3200 DATA(3,I)=DATA(3,I)-AVE3                                           PM01 950
      IND1=1                                                             PM01 960
      IF((COMP(1).GT.COMP(2)).AND.((COMP(1)-COMP(2).LT. 90.1)) IND1=2    PM01 970
      IF((COMP(2).GT.COMP(1)).AND.((COMP(2)-COMP(1).GT.269.9)) IND1=2    PM01 980
      IND2=1                                                             PM01 990
      IF(COMP(3).EQ.500.) IND2=2                                         PM011000
      IF(COMP(3).EQ.600.) IND2=3                                         PM011010
      IF(IND2.EQ.1) WRITE(6,3300)                                        PM011020
 3300 FORMAT( 1H ,40H***** VERTICAL COMPONENT = (VERT.) *****)           PM011030
      NCASE=(T3-   T1)/T2+1.001                                          PM011040
      DO 9000 I=1,NCASE                                                  PM011050
      N1= FLOAT(I-1)* T2      /.02+1.001                                 PM011060
      N2=(FLOAT(I-1)* T2+ T1)/.02+ .001                                  PM011070
      MN1=-N1+1                                                          PM011080
      KAZU=N2+MN1                                                        PM011090
      GO TO (4100,4200),IND1                                             PM011100
 4100 I1=2                                                               PM011110
      I2=1                                                               PM011120
      GO TO 4300                                                         PM011130
 4200 I1=1                                                               PM011140
      I2=2                                                               PM011150
 4300 DO 4400 J=N1,N2                                                    PM011160
      K=J+MN1                                                            PM011170
      ACC(1,K)=-DATA(I1,J)                                               PM011180
 4400 ACC(2,K)=-DATA(I2,J)                                               PM011190
      GO TO (4700,4500,4700),IND2                                        PM011200
 4600 DO 4650 J=N1,N2                                                    PM011210
      K=J+MN1                                                            PM011220
 4650 ACC( 3,K)=-DATA(3,J)                                               PM011230
      GO TO 4800                                                         PM011240
 4700 DO 4750 J=N1,N2                                                    PM011250
      K=J+MN1                                                            PM011260
 4750 ACC( 3,K)= DATA(3,J)                                               PM011270
 4800 CONTINUE                                                           PM011280
      SUM1=0.                                                            PM011290
      SUM2=0.                                                            PM011300
      SUM3=0.                                                            PM011310
      SUM4=0.                                                            PM011320
      SUM5=0.                                                            PM011330
      SUM6=0.                                                            PM011340
      DO 5100 J=1,KAZU                                                   PM011350
      XX1=ACC(1,J)                                                       PM011360
      XX2=ACC(2,J)                                                       PM011370
      XX3=ACC(3,J)                                                       PM011380
      SUM1=SUM1+XX1*XX1                                                  PM011390
      SUM2=SUM2+XX1*XX2                                                  PM011400
      SUM3=SUM3+XX1*XX3                                                  PM011410
      SUM4=SUM4+XX2*XX2                                                  PM011420
      SUM5=SUM5+XX2*XX3                                                  PM011430
 5100 SUM6=SUM6+XX3*XX3                                                  PM011440
      XX=1./FLOAT(KAZU)                                                  PM011450
      G(1,1)=SUM1*XX                                                     PM011460
      G(2,1)=SUM2*XX                                                     PM011470
      G(3,1)=SUM3*XX                                                     PM011480
      G(1,2)=SUM2*XX                                                     PM011490
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      G(2,2)=SUM4*XX                                                    PM011500
      G(3,2)=SUM5*XX                                                    PM011510
      G(1,3)=SUM3*XX                                                    PM011520
      G(2,3)=SUM5*XX                                                    PM011530
      G(3,3)=SUM6*XX                                                    PM011540
      TT1=FLOAT(N1-1)*.02                                               PM011550
      TT2=FLOAT(N2  )*.02                                               PM011560
      TT3=.5*(TT1+TT2)                                                  PM011570
CC                                                                      PM011580
      CALL SHB1 (G,3,E,V,3,3,1,1,H,P,3)                                 PM011590
CC                                                                      PM011600
      DATA PAIB /57.29579/                                              PM011610
      THT(1)=ATAN2(V(2,1),V(1,1))*PAIB                                  PM011620
      THT(2)=ATAN2(V(2,2),V(1,2))*PAIB                                  PM011630
      THT(3)=ATAN2(V(2,3),V(1,3))*PAIB                                  PM011640
      THT(4)=ACOS (       V(3,1))*PAIB                                  PM011650
      THT(5)=ACOS (       V(3,2))*PAIB                                  PM011660
      THT(6)=ACOS (       V(3,3))*PAIB                                  PM011670
      GO TO (7300,7400),IND1                                            PM011680
 7300 I1=2                                                              PM011690
      GO TO 7500                                                        PM011700
 7400 I1=1                                                              PM011710
 7500 THT(1)=COMP(I1)-THT(1)                                            PM011720
      THT(2)=COMP(I1)-THT(2)                                            PM011730
      THT(3)=COMP(I1)-THT(3)                                            PM011740
      DO 7520 J=1,6                                                     PM011750
      SUM1=THT(J)                                                       PM011760
 7510 IF(SUM1.LE.-90.) SUM1=SUM1+180.                                   PM011770
      IF(SUM1.GT. 90.) SUM1=SUM1-180.                                   PM011780
      IF((SUM1.LE.-90.).OR.(SUM1.GT. 90.)) GO TO 7510                   PM011790
 7520 THT(J)=SUM1                                                       PM011800
      DO 7540 J=4,6                                                     PM011810
 7540 IF(THT(J).LT. 0.) THT(J)=-THT(J)                                  PM011820
      DO 7560 J=1,3                                                     PM011830
 7560 E(J)=SQRT(E(J))                                                   PM011840
      IF(IPR3)  7700,7700,7599                                          PM011850
 7599 WRITE(6,7600) TT3,E(1),THT(1),THT(4),(V(1,J),J=1,3),              PM011860
     1               TT1,E(2),THT(2),THT(5),(V(2,J),J=1,3),             PM011870
     2               TT2,E(3),THT(3),THT(6),(V(3,J),J=1,3)              PM011880
 7600 FORMAT(1H0,5X,F7.3,6H (SEC),5X,15HMAJOR         = ,  F13.4,       PM011890
     1          5X,0P2F10.3,9H (DEGREE),5X,0P3F10.5,                   PM011900
     2       /1H ,5X,F7.3,6X      ,5X,15HINTERMEDIATE = ,  F13.4,       PM011910
     3          5X,0P2F10.3,9X          ,5X,0P3F10.5,                  PM011920
     4       /1H ,5X,F7.3,6X      ,5X,15HMINOR        = ,  F13.4,       PM011930
     5          5X,0P2F10.3,9X          ,5X,0P3F10.5)                  PM011940
 7700 DO 8000 J=1,3                                                     PM011950
      PSHAPE(J,I)=E(J)                                                  PM011960
      PTHETA(J,I)=THT(J)                                                PM011970
      PPHI  (J,I)=THT(J+3)                                              PM011980
 8000 CONTINUE                                                          PM011990
      PTT   (  I)=TT3                                                   PM012000
 9000 CONTINUE                                                          PM012010
      IF(IPL3) 9100,9100,9001                                           PM012020
 9001 DO 9080 J=1,3                                                     PM012030
      DATA CHK /75./                                                    PM012040
      SUM1=PTHETA(J,1)                                                  PM012050
      DO 9080 I=2,NCASE                                                 PM012060
      SUM2=PTHETA(J,I)                                                  PM012070
      IF(ABS(SUM2)-CHK) 9070,9010,9010                                  PM012080
 9010 IF(SUM1*SUM2) 9020,9070,9070                                      PM012090
 9020 PTHETA(J,I)=-SIGN(180.,SUM2)+SUM2                                 PM012100
 9070 SUM1=PTHETA(J,I)                                                  PM012110
 9080 CONTINUE                                                          PM012120
      CALL PLTTNG  (PSHAPE,PTHETA,PPHI    ,NCASE,LABEL1,LABEL2,        PM012130
     1              PTT    ,PYY    ,T3,THETA,NSKIP)                    PM012140
 9100 GO TO 1000                                                        PM012150
 9900 CALL PLTTNG  (PSHAPE,PTHETA,PPHI    ,NCASE,LABEL1,LABEL2,        PM012160
     1              PTT    ,PYY    ,T3,THETA,NSKIP)                    PM012170
      WRITE(6,9990)                                                     PM012180
 9990 FORMAT( 1H0,20X,24HJOB NORMALLY TERMINATED.)                      PM012190
      STOP                                                              PM012200
      END                                                               PM012210
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      SUBROUTINE DRCTON (OBLAT,OBLON,EPLAT,EPLON,THETA)                 DRCT   0
CC    RADIUS OF EARTH  (EQUIVALENT SPHERE)                              DRCT  10
      DATA RR/6371.2213/                                                DRCT  20
      DATA PAIA,PAIB/1.745329252E-2,57.29577961/                        DRCT  30
      OBLAT=OBLAT*PAIA                                                  DRCT  40
      OBLON=OBLON*PAIA                                                  DRCT  50
      EPLAT=EPLAT*PAIA                                                  DRCT  60
      EPLON=EPLON*PAIA                                                  DRCT  70
      AA   =EPLAT-OBLAT                                                 DRCT  80
      BB   =.5*(COS(EPLAT)+COS(OBLAT))*(EPLON-OBLON)                    DRCT  90
      THETA=-ATAN2(BB,AA)*PAIB                                          DRCT 100
      IF(THETA) 1100,1200,1200                                          DRCT 110
 1100 THETA=THETA+360.                                                  DRCT 120
 1200 DIST=RR*SQRT(AA*AA+BB*BB)                                         DRCT 130
      WRITE(6,2000) THETA,DIST                                          DRCT 140
 2000 FORMAT(/1H0,10X,32HSEISMOGRAPH STATION TO EPICENTER,              DRCT 150
     1       /1H0,20X,12HDIRECTION = ,F15.7, 9H (DEGREE),               DRCT 160
     2       /1H ,20X,12HDISTANCE  = ,F15.7,13H (KILO-METER))           DRCT 170
      RETURN                                                            DRCT 180
      END                                                               DRCT 190
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      SUBROUTINE SHB1(G,N,E,V,NEV,NVEC,IND,ITRI,H,P,NL)                 SHB1   0
C                                                                       SHB1  10
C                                                                       SHB1  20
C 195 F2/TC/SHB1                                                        SHB1  30
CC                                                                      SHB1  40
C                                                                       SHB1  50
C PURPOSE                                                               SHB1  60
C     CALCULATION OF EIGENVALUES AND EIGENVECTORS OF A REAL AND         SHB1  70
C     SYMMETRIC MATRIX.                                                 SHB1  80
C                                                                       SHB1  90
C USAGE                                                                 SHB1 100
C     CALL SHB1(G,N,E,V,NEV,NVEC,IND,ITRI,H,P,NL)                       SHB1 110
C                                                                       SHB1 120
C DESCRIPTION OF THE PARAMETERS                                         SHB1 130
C     G   THE INPUT REAL SYMMETRIC MATRIX,ARRAY(NL,NL)                  SHB1 140
C     NL  DIMENSION SIZE OF MAIN PROGAM MATRIX                          SHB1 150
C     N   THE DIMENSION OF DATA MATRIX                                  SHB1 160
C     E   THE EIGENVALUES ARE CONTAINED ON RETURN. ARRAY(NVEC), REAL    SHB1 170
C     V   THE EIGENVECTORS ARE STORED ON RETURN. I-TH COLUMN OF V       SHB1 180
C         CORRESPONS TO I-TH EIGENVALUE. ARRAY(NL,NVEC). REAL           SHB1 190
C     NVEC IF NVEC=0,ONLY EIGENVALUES ARE COMPUTED. OTHERWISE NVEC      SHB1 200
C         EIGENVECTORS ARE COMPUTED.                                    SHB1 210
C     IND IF IND=1, NEV ALGEBRAICALLY LARGEST EIGENVALUES ARE COMPUTED. SHB1 220
C         IF IND=2, NEV ALGEBRAICALLY SMALLEST EIGENVALUES ARE COMPUTED.SHB1 230
C         INTEGER                                                       SHB1 240
C     ITRI IF INPUT MATRIX IS NOT TRI-DIAGONAL ITRI=1                   SHB1 250
C         IF INPUT MATRIX IS TRI-DIAGONAL ITPI=2                        SHB1 260
C     H   H(I,1),I=1,...,N  DIAGONAL ELEMENTS OF TRI-DIAGONALIZED       SHB1 270
C         MATRIX ON RETURN.                                             SHB1 280
C         H(I,2),I=1,...,N-1 CO-DIAGONAL ELEMENTS OF TRI-DIAGONALIZED   SHB1 290
C         MATRIX ON RETURN.                                             SHB1 300
C         ARRAY H(NL,2),REAL                                            SHB1 310
C     P   WARKING STORAGE ARRAY P(N,5), REAL                            SHB1 320
C                                                                       SHB1 330
C REMARKS                                                               SHB1 340
C     THE ORIGINAL MATRIX IS DESTROYED.                                 SHB1 350
C     NVEC MUST NOT EXCEED NEV                                          SHB1 360
C     IF INPUT ORIGINAL MATRIX IS TRI-DIAGONAL,STORE THE DIAGONAL       SHB1 370
C     ELEMENTS IN H(I,1),I=1,...,N, AND THE CO-DIAGONAL ELEMENTS IN     SHB1 380
C     H(2,2),I=1,...,N-1, AND SET ITRI=2 WHEN CALLING THIS SUBROUTINE,  SHB1 390
C     IN THIS CASE ARRAY G IS 1 BY 1 IN CALLING PROGRAM.                SHB1 400
C SUBROUTINE AND FUNCTION SUBPROGRAMS REQUIRED                          SHB1 410
C                                                                       SHB1 420
C     NONE                                                              SHB1 430
C                                                                       SHB1 440
C METHOD                                                                SHB1 450
C     REDUCE A MATRIX TO TRIDIAGONAL FORM BY HOUSEHOLDERS               SHB1 460
C     COMPUTE EIGENVALUES BY BISECTION METHOD.                          SHB1 470
C     COMPUTE EIGENVECTORS BY INVERSE ITERATION.                        SHB1 480
C     RALSTON AND WILF,MATHEMATICAL METHODS FOR DIGITAL COMPUTERS,VOL2, SHB1 490
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C       1968 PP 94-159.                                                 SHB1 500
C                                                                       SHB1 510
C                                                                       SHB1 520
      DIMENSION G(NL,NL),E(NL),V(NL,NL),H(NL,2),P(NL,5)                 SHB1 530
      REAL L                                                            SHB1 540
      LOGICAL FIRST                                                     SHB1 550
      IF ((NL-N).LT.0) RETURN                                           SHB1 560
      IF(N.LE.1) RETURN                                                 SHB1 570
C  TRI-DIAGONALIZATION OF GIVEN MATRIX BY HOUSEHOLDER'S METHOD          SHB1 580
      EPSS=1.0E-24                                                      SHB1 590
      NM1=N-1                                                           SHB1 600
      GO TO (100,200),ITRI                                              SHB1 610
  100 IF(N.EQ.2) GO TO 9                                                SHB1 620
      NM2=N-2                                                           SHB1 630
      DO 8 I=1,NM2                                                      SHB1 640
      IP1=I+1                                                           SHB1 650
      SS=0.                                                             SHB1 660
      GK=G(IP1,I)                                                       SHB1 670
      DO 1 J=IP1,N                                                      SHB1 680
    1 SS=SS+G(J,I)*G(J,I)                                               SHB1 690
      IF(SS.LT.EPSS) GO TO 89                                           SHB1 700
      S= SQRT(SS)                                                       SHB1 710
      IF(GK.LT.0.0) S=-S                                                SHB1 720
      H(I,1)=G(I,I)                                                     SHB1 730
      H(I,2)=-S                                                         SHB1 740
      TT=0.                                                             SHB1 750
      TT=1.0E+0/(SS+GK*S)                                               SHB1 760
      T=GK+S                                                            SHB1 770
      G(IP1,I)=T                                                        SHB1 780
      P(IP1,3)=T                                                        SHB1 790
      IP2=I+2                                                           SHB1 800
      DO 2 J=IP2,N                                                      SHB1 810
    2 P(J,3)=G(J,I)                                                     SHB1 820
      DO 4 J=IP1,N                                                      SHB1 830
      T=0.0                                                             SHB1 840
      DO 3 K=IP1,N                                                      SHB1 850
    3 T=T+G(K,J)*P(K,3)                                                 SHB1 860
    4 P(J,1)=T*TT                                                       SHB1 870
      SS=0.                                                             SHB1 880
      DO 5 K=IP1,N                                                      SHB1 890
    5 SS=SS+P(K,3)*P(K,1)                                               SHB1 900
      SS=0.5E+0*SS*TT                                                   SHB1 910
      DO 6 K=IP1,N                                                      SHB1 920
    6 P(K,2)=P(K,1)-SS*P(K,3)                                           SHB1 930
      DO 7 J=IP1,N                                                      SHB1 940
      DO 7 K=J,N                                                        SHB1 950
      G(K,J)=G(K,J)-(P(J,2)*P(K,3)+P(K,2)*P(J,3))                       SHB1 960
    7 G(J,K)=G(K,J)                                                     SHB1 970
      GO TO 8                                                           SHB1 980
   89 TT=0.0E0                                                          SHB1 990
      H(I,1)=G(I,I)                                                     SHB1000
      H(I,2)=0.0E0                                                      SHB1010
    8 G(I,I)=TT                                                         SHB1020
    9 H(NM1,1)=G(NM1,NM1)                                               SHB1030
      H(NM1,2)=G(NM1,N)                                                 SHB1040
      H(N,1)=G(N,N)                                                     SHB1050
      H(N,2)=0.                                                         SHB1060
  200 CONTINUE                                                          SHB1070
C  CALCULATION OF EIGENVALUES OF TRANSFORMED MATRIX BY BINARY CHOPPING  SHB1080
      TT=ABS(H(1,1))+ABS(H(1,2))                                        SHB1090
      DO 10 I=2,N                                                       SHB1100
      S=ABS(H(I,1))+ABS(H(I,2))+ABS(H(I-1,2))                           SHB1110
C  10 TT=MAX1(TT,S)                                                     SHB1120
   10 TT=AMAX1(TT,S)                                                    SHB1130
      DO 11 I=1,N                                                       SHB1140
   11 P(I,3)=H(I,2)*H(I,2)                                              SHB1150
      ZERO=1.0E-38                                                      SHB1160
      K=1                                                               SHB1170
      IF(IND.EQ.2) TT=-TT                                               SHB1180
      U=TT                                                              SHB1190
      DO 12 I=1,NEV                                                     SHB1200
   12 E(I)=-TT                                                          SHB1210
   13 L=E(K)                                                            SHB1220
      EPS=1.0E-7*ABS(U)                                                 SHB1230
   14 T=0.5E+0*(L+U)                                                    SHB1240
      IF((ABS(U-T).LE.EPS ).OR.(ABS(T-L).LE.EPS)) GO TO 30              SHB1250
      J=0                                                               SHB1260
      I=1                                                               SHB1270
   16 S=H(I,1)-T                                                        SHB1280
   18 IF(S.GE.-ZERO) J=J+1                                              SHB1290
      IF(ABS(S).LE.ZERO) GO TO 20                                       SHB1300
      I=I+1                                                             SHB1310
      IF(I.GT.N) GO TO 21                                               SHB1320
      S=H(I,1)-T-P(I-1,3)/S                                             SHB1330
      GO TO 18                                                          SHB1340
   20 I=I+2                                                             SHB1350
      IF (I.LE.N) GO TO 16                                              SHB1360
   21 GO TO (23,22), IND                                                SHB1370
   22 J=N-J                                                             SHB1380
   23 IF(J.GE.K) GO TO 24                                               SHB1390
      U=T                                                               SHB1400
      GO TO 14                                                          SHB1410
   24 L=T                                                               SHB1420
      M=MIN0(J,NEV)                                                     SHB1430
      DO 26 I=K,M                                                       SHB1440
   26 E(I)=T                                                            SHB1450
      GO TO 14                                                          SHB1460
   30 E(K)=T                                                            SHB1470
      K=K+1                                                             SHB1480
      IF(K.LE.NEV) GO TO 13                                             SHB1490
      IF(NVEC.EQ.0) RETURN                                              SHB1500
C CALCULATION OF EIGENVECTORS BY WIELANDT'S INVERSE ITERATION           SHB1510
C     IR=1234567                                                        SHB1520
      DO 600 I=1,NVEC                                                   SHB1530
      DO 44 J=1,N                                                       SHB1540
      P(J,1)=0.                                                         SHB1550
      P(J,2)=H(J,2)                                                     SHB1560
      P(J,3)=H(J,1)-E(I)                                                SHB1570
   44 V(J,I)=1.0E+0                                                     SHB1580
      FIRST=.TRUE.                                                      SHB1590
      DO 50 J=1,NM1                                                     SHB1600
      PJ3=P(J,3)                                                        SHB1610
      HJ1=H(J,2)                                                        SHB1620
      IF(ABS(PJ3).LT.ABS(HJ1)) GO TO 46                                 SHB1630
      SS=HJ1/PJ3                                                        SHB1640
      P(J,4)=0.                                                         SHB1650
      GO TO 48                                                          SHB1660
   46 SS=PJ3/HJ1                                                        SHB1670
      P(J,4)=1.0E+0                                                     SHB1680
      P(J,3)=H(J,2)                                                     SHB1690
      T=P(J+1,3)                                                        SHB1700
      P(J+1,3)=P(J,2)                                                   SHB1710
      P(J,2)=T                                                          SHB1720
      P(J,1)=P(J+1,2)                                                   SHB1730
      P(J+1,2)=0.                                                       SHB1740
   48 P(J,5)=SS                                                         SHB1750
      P(J+1,2)=P(J+1,2)-SS*P(J,1)                                       SHB1760
      P(J+1,3)=P(J+1,3)-SS*P(J,2)                                       SHB1770
C     IF (P(J,3).EQ.0.)  P(J,3)=1.0D-30                                 SHB1780
      IF (P(J,3).EQ.0.)  P(J,3)=1.0E-30                                 SHB1790
   50 CONTINUE                                                          SHB1800
      IF(P(N,3).EQ.0.) P(N,3)=1.0E-30                                   SHB1810
      IF(I.EQ.1.OR.ABS(E(I)-E(I-1)).GE.TT*1.0E-6) GO TO 54              SHB1820
      DO 52 J=1,N                                                       SHB1830
C     IR=IR*48828125                                                    SHB1840
C  52 V(J,I)=FLOAT(IR)*0.46566613E-9                                    SHB1850
   52 V(J,I)=PANF(0.0)                                                  SHB1860
C  54 CALL OVERFL(II)                                                   SHB1870
   54 CONTINUE                                                          SHB1880
      DO 66 J=1,N                                                       SHB1890
      K=N-J+1                                                           SHB1900
      T=V(K,I)                                                          SHB1910
   62 S=0.                                                              SHB1920
      SS=0.                                                             SHB1930
      IF(K.LT.N) S=V(K+1,I)                                             SHB1940
      IF(K.LT.NM1) SS=V(K+2,I)                                          SHB1950
      V(K,I)=(T-S*P(K,2)-SS*P(K,1))/P(K,3)                              SHB1960
      CALL OVERFL(II)                                                   SHB1970
CC    II=LEGVAR(V(K,I))                                                 SHB1980
      IF(II.NE.1) GO TO 66                                              SHB1990
```

```
      DO 64 M=1,N                                                       SHB12000
   64 V(M,I)=V(M,I)*1.0E-5                                              SHB12010
      T=T*1.0E-5                                                        SHB12020
      GO TO 62                                                          SHB12030
   66 CONTINUE                                                          SHB12040
      IF (.NOT.FIRST) GO TO 74                                          SHB12050
      FIRST=.FALSE.                                                     SHB12060
      DO 70 J=1,NM1                                                     SHB12070
      JP1=J+1                                                           SHB12080
      IF(P(J,4).NE.0.0) GO TO 68                                        SHB12090
      V(JP1,I)=V(JP1,I)-P(J,5)*V(J,I)                                   SHB12100
      GO TO 70                                                          SHB12110
   68 T=V(J,I)                                                          SHB12120
      V(J,I)=V(JP1,I)                                                   SHB12130
      V(JP1,I)=T-P(J,5)*V(JP1,I)                                        SHB12140
   70 CONTINUE                                                          SHB12150
      GO TO 54                                                          SHB12160
   74 GO TO (400,500),ITRI                                              SHB12170
  400 IF(N.EQ.2) GO TO 500                                              SHB12180
      DO 78 J=1,NM2                                                     SHB12190
      T=0.                                                              SHB12200
      K=N-J-1                                                           SHB12210
      M=K+1                                                             SHB12220
      DO 76 KK=M,N                                                      SHB12230
   76 T=T+G(KK,K)*V(KK,I)                                               SHB12240
      T=T*G(K,K)                                                        SHB12250
      DO 78 KK=M,N                                                      SHB12260
   78 V(KK,I)=V(KK,I)-T*G(KK,K)                                         SHB12270
  500 T=0.                                                              SHB12280
      DO 80 J=1,N                                                       SHB12290
      SS=ABS(V(J,I))                                                    SHB12300
   80 IF(SS.GT.T) T=SS                                                  SHB12310
      DO 81 J=1,N                                                       SHB12320
   81 V(J,I)=V(J,I)/T                                                   SHB12330
      T=0.                                                              SHB12340
      DO 82 J=1,N                                                       SHB12350
   82 T=T+V(J,I)*V(J,I)                                                 SHB12360
      T=SQRT(T)                                                         SHB12370
      DO 600 J=1,N                                                      SHB12380
  600 V(J,I)=V(J,I)/T                                                   SHB12390
      RETURN                                                            SHB12400
      END                                                               SHB12410
```

```
      SUBROUTINE PLTING  (PS,PT,PP,NCASE,LINE1,LINE2,                   PLTG   0
     1                    XX,YY,TEND,THT,INDEX)                         PLTG  10
      DIMENSION PS(3, 1),PT(3, 1),PP(3, 1),XX( 1),YY( 1),              PLTG  20
     1          LINE1(1),LINE2(1)                                       PLTG  30
      DIMENSION GIVEN(5),SPECS(30)                                      PLTG  40
      DIMENSION TT2(2),YY2(2)                                           PLTG  50
      REAL MAX                                                          PLTG  60
      IF(INDEX.EQ.999) GO TO 9000                                       PLTG  70
      I=IFIX(TEND/5.+ .99 )                                             PLTG  80
      TT3=FLOAT(I)*5.                                                   PLTG  90
      LINE1(5)=0                                                        PLTG 100
      LINE2(7)=0                                                        PLTG 110
      MAX=0.                                                            PLTG 120
      DO 1200 I=1,NCASE                                                 PLTG 130
      IF(MAX-PS(1,I)) 1100,1200,1200                                    PLTG 140
 1100 MAX=PS(1,I)                                                       PLTG 150
 1200 CONTINUE                                                          PLTG 160
C  TO DETERMINE LAYOUT OF Y-AXIS SCALE                                  PLTG 170
      GIVEN(1)=MAX                                                      PLTG 180
      GIVEN(2)=0.                                                       PLTG 190
      GIVEN(3)=3.                                                       PLTG 200
      GIVEN(4)=2.                                                       PLTG 210
      GIVEN(5)=1.                                                       PLTG 220
          CALL EAGLIY (GIVEN,SPECS)                                     PLTG 230
      DM 5=SPECS( 5)                                                    PLTG 240
      DM 6=SPECS( 6)                                                    PLTG 250
      DM 8=SPECS( 8)                                                    PLTG 260
      DM10=SPECS(10)                                                    PLTG 270
      GIVEN(3)=4.                                                       PLTG 280
          CALL EAGLIY (GIVEN,SPECS)                                     PLTG 290
      IF(SPECS( 8).GE.DM 8) GO TO 1500                                  PLTG 300
       SPECS( 5)=DM 5                                                   PLTG 310
       SPECS( 6)=DM 6                                                   PLTG 320
       SPECS( 8)=DM 8                                                   PLTG 330
       SPECS(10)=DM10                                                   PLTG 340
 1500 GIVEN(3)=5.                                                       PLTG 350
      DM 5=SPECS( 5)                                                    PLTG 360
      DM 6=SPECS( 6)                                                    PLTG 370
      DM 8=SPECS( 8)                                                    PLTG 380
      DM10=SPECS(10)                                                    PLTG 390
          CALL EAGLIY (GIVEN,SPECS)                                     PLTG 400
      IF(SPECS( 8).GT.DM 8) GO TO 1600                                  PLTG 410
       SPECS( 5)=DM 5                                                   PLTG 420
       SPECS( 6)=DM 6                                                   PLTG 430
       SPECS( 8)=DM 8                                                   PLTG 440
       SPECS(10)=DM10                                                   PLTG 450
 1600 CONTINUE                                                          PLTG 460
       SPECS( 1)=1.                                                     PLTG 470
       SPECS( 2)=1.                                                     PLTG 480
      TL=.25                                                            PLTG 490
      IF(TT3.LE.15.) TL=.5                                              PLTG 500
       SPECS( 7)=TT3*TL                                                 PLTG 510
       SPECS( 9)=TT3/5.+.001                                            PLTG 520
      IF(TL.EQ. .5) SPECS( 9)=2.*SPECS( 9)                              PLTG 530
       SPECS(11)=1.                                                     PLTG 540
       SPECS(12)=99.                                                    PLTG 550
C  RECTANGULAR GRID PLOTTING FOR SHAPE FUNCTION                         PLTG 560
          CALL GDLILI (SPECS)                                           PLTG 570
       SPECS( 9)=TT3+.001                                               PLTG 580
      IF(TL.EQ. .5) SPECS( 9)=2.*SPECS( 9)                              PLTG 590
          CALL AXLILI (SPECS)                                           PLTG 600
       SPECS( 3)=TT3                                                    PLTG 610
       SPECS( 4)=0.                                                     PLTG 620
       SPECS( 9)=TT3/5.+.001                                            PLTG 630
      IF(TL.EQ. .5) SPECS( 9)=2.*SPECS( 9)                              PLTG 640
       SPECS(17)= .15                                                   PLTG 650
       SPECS(18)= .15                                                   PLTG 660
       SPECS(19)=0.                                                     PLTG 670
       SPECS(21)=1.                                                     PLTG 680
       SPECS(24)= .1                                                    PLTG 690
       SPECS(28)=1.                                                     PLTG 700
          CALL NODLIB (SPECS)                                           PLTG 710
       SPECS(20)=0.                                                     PLTG 720
       SPECS(26)= .1                                                    PLTG 730
          CALL NODLIL (SPECS)                                           PLTG 740
       SPECS(13)=FLOAT(NCASE)+ .001                                     PLTG 750
       SPECS(14)=1.                                                     PLTG 760
       SPECS(15)=1.                                                     PLTG 770
C  PLOT SHAPE FUNCTION                                                  PLTG 780
      DO 2200 J=1,7                                                     PLTG 790
      DO 2100 I=1,NCASE                                                 PLTG 800
 2100 YY(I)=PS(J,I)                                                     PLTG 810
 2200     CALL PLT2 (J,SPECS,XX,YY)                                     PLTG 820
       SPECS(17)= .18                                                   PLTG 830
       SPECS(18)= .18                                                   PLTG 840
          CALL TITLEB (11HTIME (SEC.),SPECS)                            PLTG 850
          CALL TITLEL ( 5HSIGMA      ,SPECS)                            PLTG 860
C  RECTANGULAR GRID PLOTTING FOR THETA                                  PLTG 870
       SPECS( 2)=3.5                                                    PLTG 880
       SPECS( 8)=1.8                                                    PLTG 890
       SPECS(10)=4.                                                     PLTG 900
          CALL GDLILI (SPECS)                                           PLTG 910
       SPECS(10)=12.                                                    PLTG 920
          CALL AXLILI (SPECS)                                           PLTG 930
       SPECS( 5)= 90.                                                   PLTG 940
       SPECS( 6)=-90.                                                   PLTG 950
       SPECS(10)=4.                                                     PLTG 960
       SPECS(17)= .15                                                   PLTG 970
       SPECS(18)= .15                                                   PLTG 980
       SPECS(25)= .1                                                    PLTG 990
       SPECS(28)=  0.                                                   PLTG1000
          CALL NODLIL (SPECS)                                           PLTG1010
C  PLOT (THETA)                                                         PLTG1020
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      DO 3150 J=1,3                                                     PLTG1030
      DO 3100 I=1,NCASE                                                 PLTG1040
 3100 YY(I)=PT(J,I)                                                     PLTG1050
 3150      CALL PLT2 (J,SPECS,XX,YY)                                   PLTG1060
      THETA=THT                                                         PLTG1070
 3200 IF(THETA.LE.-90.) THETA=THETA+180.                                PLTG1080
      IF(THETA.GT. 90.) THETA=THETA-180.                                PLTG1090
      IF((THETA.LE.-90.).OR.(THETA.GT. 90.)) GO TO 3200                 PLTG1100
      TT2(1)=TT3                                                        PLTG1110
      TT2(2)=0.                                                         PLTG1120
      YY2(1)=THETA                                                      PLTG1130
      YY2(2)=THETA                                                      PLTG1140
      DASH= .2                                                          PLTG1150
      SPACE= .1                                                         PLTG1160
       SPECS(13)=2.001                                                  PLTG1170
          CALL DLLILI (TT2,YY2,DASH,SPACE,SPECS)                        PLTG1180
       SPECS(17)= .18                                                   PLTG1190
       SPECS(18)= .18                                                   PLTG1200
          CALL TITLEL (5HTHETA,SPECS)                                   PLTG1210
C  RECTANGULAR GRID PLOTTING FOR PHI                                    PLTG1220
       SPECS( 2)=5.7                                                    PLTG1230
       SPECS( 8)= .9                                                    PLTG1240
       SPECS(10)=3.                                                     PLTG1250
          CALL GDLILI (SPECS)                                           PLTG1260
       SPECS(10)= 9.                                                    PLTG1270
          CALL AXLILI (SPECS)                                           PLTG1280
       SPECS( 5)=90.                                                    PLTG1290
       SPECS( 6)= 0.                                                    PLTG1300
       SPECS(10)=3.                                                     PLTG1310
       SPECS(17)= .15                                                   PLTG1320
       SPECS(18)= .15                                                   PLTG1330
       SPECS(26)= .1                                                    PLTG1340
          CALL NODLIL (SPECS)                                           PLTG1350
C  PLOT (PHI)                                                           PLTG1360
       SPECS(13)=FLOAT(NCASE)+ .001                                     PLTG1370
      DO 4200 J=1,3                                                     PLTG1380
      DO 4100 I=1,NCASE                                                 PLTG1390
 4100 YY(I)=PP(J,I)                                                     PLTG1400
 4200      CALL PLT2 (J,SPECS,XX,YY)                                   PLTG1410
       SPECS(17)= .18                                                   PLTG1420
       SPECS(18)= .18                                                   PLTG1430
          CALL TITLEL (3HPHI,SPECS)                                     PLTG1440
       SPECS( 9)=TT3+.001                                               PLTG1450
      IF(TL.EQ. .5) SPECS( 9)=2.*SPECS( 9)                              PLTG1460
       SPECS(25)= .0                                                    PLTG1470
          CALL SAXLIT (SPECS)                                           PLTG1480
       SPECS( 9)=TT3/5.+.001                                            PLTG1490
      IF(TL.EQ. .5) SPECS( 9)=2.*SPECS( 9)                              PLTG1500
       SPECS(17)= .15                                                   PLTG1510
       SPECS(18)= .15                                                   PLTG1520
       SPECS(25)= .2                                                    PLTG1530
       SPECS(29)=1.                                                     PLTG1540
          CALL NODLIT (SPECS)                                           PLTG1550
       SPECS(22)=1.                                                     PLTG1560
       SPECS(23)=7.4                                                    PLTG1570
      RULE=1.                                                           PLTG1580
          CALL TITLEG (RULE,LINE2,SPECS)                                PLTG1590
       SPECS(17)= .18                                                   PLTG1600
       SPECS(18)= .18                                                   PLTG1610
       SPECS(23)=7.7                                                    PLTG1620
          CALL TITLEG (RULE,LINE1,SPECS)                                PLTG1630
          CALL NXTERM (SPECS)                                           PLTG1640
      RETURN                                                            PLTG1650
 9000 WRITE(6,9100)                                                     PLTG1660
 9100 FORMAT(1H0,20X,19HPLOTTER TERMINATED.)                            PLTG1670
       SPECS(12)=99.                                                    PLTG1680
          CALL GDSEND (SPECS)                                           PLTG1690
      RETURN                                                            PLTG1700
      END                                                               PLTG1710
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      SUBROUTINE PLT2 (I,S,XX,YY)                                       PLT    0
      DIMENSION S(1),XX(1),YY(1)                                        PLT   10
      GO TO (1000,2000,3000),I                                          PLT   20
 1000     CALL SLLILI (XX,YY,S)                                        PLT   30
      GO TO 5000                                                        PLT   40
 2000 DASH = .1                                                         PLT   50
      GO TO 4000                                                        PLT   60
 3000 DASH = .04                                                        PLT   70
 4000 SPACE= .05                                                        PLT   80
          CALL SLLILI (XX,YY,DASH,SPACE,S)                              PLT   90
 5000 RETURN                                                            PLT  100
      END                                                               PLT  110
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      PROGRAM PGM11  (INPUT,OUTPUT,PUNCH,                                PM11   0
     1                TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=PUNCH,              PM11  10
     2                TAPE1,TAPE99)                                      PM11  20
COMMENT       SUBROUTINES, REQUIRED                                      PM11  30
C   SUBROUTINE DRCTON                                                    PM11  40
C   SUBROUTINE FFTR                                                      PM11  50
C   SUBROUTINE SHB1                                                      PM11  60
C   SUBROUTINE FPLTNG                                                    PM11  70
      DIMENSION CORTIL(200),ICOR(100),FCOR(100)                          PM11  80
      DIMENSION DATA(3,1500)                                             PM11  90
      DIMENSION ACOSI(3,1025),BSINE(3,1025)                              PM11 100
      DIMENSION G(3,3),E(3),V(3,3),H(3,2),P(3,5)                         PM11 110
      DIMENSION COMP(3),THT(6)                                           PM11 120
      DIMENSION PSHAPE(3, 60),PTHETA(3, 60),PPHI  (3, 60),               PM11 130
     1          PFF   (   60),PYY   (   60),LABEL1(5),LABEL2(7)          PM11 140
      DIMENSION A1(1025),B1(1025),WORK(2048),S(511)                      PM11 150
      INTEGER CORTIL                                                     PM11 160
      EQUIVALENCE (ACOSI(1),CORTIL(1)),(ACOSI(201),ICOR(1)),             PM11 170
     1            (ACOSI(301),FCOR(1))                                   PM11 180
CC                                                                       PM11 190
CC  M1   =  FREQUENCY LENGTH OF WINDOW                                   PM11 200
CC  M2   =  FREQUENCY, SKIPPED                                           PM11 210
CC  M3   =  TERMINATE FREQUENCY                                          PM11 220
CC                                                                       PM11 230
      CALL SETFXB (1,2500,100)                                           PM11 240
 1000 READ(5,101) NSKIP,M1,M2,M3,IPL3,IPR3                               PM11 250
      IF(NSKIP.EQ.999) GO TO 9900                                        PM11 260
  101 FORMAT(6I8)                                                        PM11 270
  102 FORMAT( 8A10)                                                      PM11 280
  111 FORMAT(10I10)                                                      PM11 290
  113 FORMAT(10F10.1)                                                    PM11 300
      IF(NSKIP.EQ.0) GO TO 1200                                          PM11 310
      NSKIP=3*NSKIP                                                      PM11 320
      CALL SKIPF (5LTAPE1,NSKIP,3HEOF)                                   PM11 330
 1200 WRITE(6,200)                                                       PM11 340
CC     READING MAGNETIC FILESETS                                         PM11 350
      DO 2000 J=1,3                                                      PM11 360
      READ(1,102) CORTIL                                                 PM11 370
 1400 WRITE(6,210) J,(CORTIL(I),I=1,8),(CORTIL(I),I=41,56),              PM11 380
     1              (CORTIL(I),I=169,176)                                PM11 390
      READ(1,111) ICOR                                                   PM11 400
      COMP(J)=FLOAT(ICOR(27))                                            PM11 410
      KAZU=ICOR(53)                                                      PM11 420
      READ(1,113) FCOR                                                   PM11 430
      IF(KAZU.GT.1500) KAZU=1500                                         PM11 440
      READ(1,113) (DATA(J,I),I=1,KAZU)                                   PM11 450
      CALL SKIPF (5LTAPE1,    1,3HEOF)                                   PM11 460
 2000 CONTINUE                                                           PM11 470
      DO 2100 I=1,4                                                      PM11 480
 2100 LABEL1(I)=CORTIL(I+40)                                             PM11 490
      DO 2110 I=1,6                                                      PM11 500
 2110 LABEL2(I)=CORTIL(I+48)                                             PM11 510
CC     PRINT OUT INFORMATIONS OF EPICENTER AND STATION                   PM11 520
      WRITE(6,220 ) (ICOR(I),I=16,21)                                    PM11 530
      WRITE(6,230 ) (ICOR(I),I=10,15)                                    PM11 540
      EPLAT=FLOAT(    ICOR(16) )+FLOAT(ICOR(17))/60.                     PM11 550
     1                          +FLOAT(ICOR(18))/3600.                   PM11 560
      EPLON=ABS(FLOAT(ICOR(19)))+FLOAT(ICOR(20))/60.                     PM11 570
     1                          +FLOAT(ICOR(21))/3600.                   PM11 580
      OBLAT=FLOAT(    ICOR(10) )+FLOAT(ICOR(11))/60.                     PM11 590
     1                          +FLOAT(ICOR(12))/3600.                   PM11 600
      OBLON=ABS(FLOAT(ICOR(13)))+FLOAT(ICOR(14))/60.                     PM11 610
     1                          +FLOAT(ICOR(15))/3600.                   PM11 620
CC                                                                       PM11 630
  200 FORMAT(1H1)                                                        PM11 640
  210 FORMAT(1HO     ,13HRECORD NO. = ,I2,   /1H ,5X,8A10,               PM11 650
     1           /1H , 5X,8A10,/1H , 5X,8A10,/1H , 5X,8A10)              PM11 660
  220 FORMAT(/1HO,10X,12HEPICENTER = ,3I4,8H N (LAT),                    PM11 670
     1        /1H ,22X,               3I4,8H W (LON))                   PM11 680
  230 FORMAT(/1H ,10X,12HSTATION   = ,3I4,8H N (LAT),                    PM11 690
     1        /1H ,22X,               3I4,8H W (LON))                   PM11 700
CC                                                                       PM11 710
      CALL DRCTON  (OBLAT,OBLON,EPLAT,EPLON,THETA)                       PM11 720
      NFFT=2048                                                          PM11 730
      DFREQ=1./( .02*FLOAT(NFFT))                                        PM11 740
      KP1=KAZU+1                                                         PM11 750
      KP2=NFFT/2+1                                                       PM11 760
      IND1=1                                                             PM11 770
      IF((COMP(1).GT.COMP(2)).AND.(COMP(1)-COMP(2).LT. 90.1)) IND1=2     PM11 780
      IF((COMP(2).GT.COMP(1)).AND.(COMP(2)-COMP(1).GT.269.9)) IND1=2     PM11 790
      IND2=1                                                             PM11 800
      IF(COMP(3).EQ.500.) IND2=2                                         PM11 810
      IF(COMP(3).EQ.600.) IND2=3                                         PM11 820
      IF(IND2.EQ.1) WRITE(6,3300)                                        PM11 830
      F1=FLOAT(M1)*DFREQ                                                 PM11 840
      F2=FLOAT(M2)*DFREQ                                                 PM11 850
      F3=FLOAT(M3)*DFREQ                                                 PM11 860
      WRITE(6,3050) F1,F2,F3                                             PM11 870
 3050 FORMAT(/1H0,25H     LENGTH OF WINDOW  = ,F15.7,10H (1./SEC.),      PM11 880
     1       /1H ,25H     INTERVAL, SKIPPED = ,F15.7,10H (1./SEC.),      PM11 890
     2       /1H ,25HTERMINATE LENGTH       = ,F15.7,10H (1./SEC.))     PM11 900
      GO TO (3110,3130),IND1                                             PM11 910
 3110 DO 3120 I=1,KAZU                                                   PM11 920
      XX       = DATA(1,I)                                               PM11 930
      DATA(1,I)=-DATA(2,I)                                               PM11 940
 3120 DATA(2,I)=-XX                                                      PM11 950
      GO TO 3150                                                         PM11 960
 3130 DO 3140 I=1,KAZU                                                   PM11 970
      DATA(1,I)=-DATA(1,I)                                               PM11 980
 3140 DATA(2,I)=-DATA(2,I)                                               PM11 990
 3150 GO TO (3200,3160,3200),IND2                                        PM111000
 3160 DO 3170 I=1,KAZU                                                   PM111010
 3170 DATA(3,I)=-DATA(3,I)                                               PM111020
 3200 CONTINUE                                                           PM111030
 3300 FORMAT( 1H ,40H***** VERTICAL COMPONENT = (VERT.) *****)           PM111040
      DO 3800 J=1,3                                                      PM111050
      DO 3500 I=1,KAZU                                                   PM111060
 3500 WORK(I)=DATA(J,I)                                                  PM111070
      DO 3600 I=KP1,NFFT                                                 PM111080
 3600 WORK(I)=0.                                                         PM111090
      CALL FFTR (WORK,   A1,   B1,NFFT,1,S, .02)                         PM111100
      DO 3700 I=1,KP2                                                    PM111110
      ACOSI(J,I)=A1(I)                                                   PM111120
 3700 BSINE(J,I)=B1(I)                                                   PM111130
 3800 CONTINUE                                                           PM111140
      NCASE=(M3-M1/2)/M2 + 1                                             PM111150
      DO 9000 I=1,NCASE                                                  PM111160
      N1=(I-1)*M2+ 1                                                     PM111170
      N2=(I-1)*M2+M1                                                     PM111180
      DO 4800 J=1,3                                                      PM111190
      DO 4500 K=1,KP2                                                    PM111200
      A1(K)=0.                                                           PM111210
 4500 B1(K)=0.                                                           PM111220
      DO 4600 K=N1,N2                                                    PM111230
      A1(K)=ACOSI(J,K)                                                   PM111240
 4600 B1(K)=BSINE(J,K)                                                   PM111250
      CALL FFTR (WORK,   A1,   B1,NFFT,2,S, .02)                         PM111260
      DO 4700 K=1,KAZU                                                   PM111270
 4700 DATA(J,K)=WORK(K)                                                  PM111280
 4800 CONTINUE                                                           PM111290
      SUM1=0.                                                            PM111300
      SUM2=0.                                                            PM111310
      SUM3=0.                                                            PM111320
      SUM4=0.                                                            PM111330
      SUM5=0.                                                            PM111340
      SUM6=0.                                                            PM111350
      DO 5100 J=1,KAZU                                                   PM111360
      XX1=DATA(1,J)                                                      PM111370
      XX2=DATA(2,J)                                                      PM111380
      XX3=DATA(3,J)                                                      PM111390
      SUM1=SUM1+XX1*XX1                                                  PM111400
      SUM2=SUM2+XX1*XX2                                                  PM111410
      SUM3=SUM3+XX1*XX3                                                  PM111420
      SUM4=SUM4+XX2*XX2                                                  PM111430
      SUM5=SUM5+XX2*XX3                                                  PM111440
 5100 SUM6=SUM6+XX3*XX3                                                  PM111450
      XX=1./FLOAT(KAZU)                                                  PM111460
      G(1,1)=SUM1*XX                                                     PM111470
      G(2,1)=SUM2*XX                                                     PM111480
      G(3,1)=SUM3*XX                                                     PM111490
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      G(1,2)=SUM2*XX                                                    PM111500
      G(2,2)=SUM4*XX                                                    PM111510
      G(3,2)=SUM5*XX                                                    PM111520
      G(1,3)=SUM3*XX                                                    PM111530
      G(2,3)=SUM5*XX                                                    PM111540
      G(3,3)=SUM6*XX                                                    PM111550
      FF3=.5*FLOAT(N1+N2-1)*DFREQ                                       PM111560
CC                                                                      PM111570
      CALL SHB1 (G,3,E,V,3,3,1,1,H,P,3)                                 PM111580
CC                                                                      PM111590
      DATA PAIR /57.29579/                                              PM111600
      THT(1)=ATAN2(V(2,1),V(1,1))*PAIR                                  PM111610
      THT(2)=ATAN2(V(2,2),V(1,2))*PAIR                                  PM111620
      THT(3)=ATAN2(V(2,3),V(1,3))*PAIR                                  PM111630
      THT(4)=ACOS (       V(3,1))*PAIR                                  PM111640
      THT(5)=ACOS (       V(3,2))*PAIR                                  PM111650
      THT(6)=ACOS (       V(3,3))*PAIR                                  PM111660
      GO TO (7300,7400),IND1                                            PM111670
 7300 I1=2                                                              PM111680
      GO TO 7500                                                        PM111690
 7400 I1=1                                                              PM111700
 7500 THT(1)=COMP(I1)-THT(1)                                            PM111710
      THT(2)=COMP(I1)-THT(2)                                            PM111720
      THT(3)=COMP(I1)-THT(3)                                            PM111730
      DO 7520 J=1,6                                                     PM111740
      SUM1=THT(J)                                                       PM111750
 7510 IF(SUM1.LE.-90.) SUM1=SUM1+180.                                   PM111760
      IF(SUM1.GT. 90.) SUM1=SUM1-180.                                   PM111770
      IF((SUM1.LE.-90.).OR.(SUM1.GT. 90.)) GO TO 7510                   PM111780
 7520 THT(J)=SUM1                                                       PM111790
      DO 7540 J=4,6                                                     PM111800
 7540 IF(THT(J).LT. 0.) THT(J)=-THT(J)                                  PM111810
      DO 7560 J=1,3                                                     PM111820
 7560 E(J)=SQRT(E(J))                                                   PM111830
      IF(IPR3)  7700,7700,7599                                          PM111840
 7599 WRITE(6,7600) FF3,E(1),THT(1),THT(4),(V(1,J),J=1,3),              PM111850
     1               N1,E(2),THT(2),THT(5),(V(2,J),J=1,3),              PM111860
     2               N2,E(3),THT(3),THT(6),(V(3,J),J=1,3)               PM111870
 7600 FORMAT(1H0,5X,F7.3,6H (HZ.),5X,15HMAJOR         = ,  F13.4,       PM111880
     1           5X,0P2F10.3,9H (DEGREE),5X,0P3F10.5,                   PM111890
     2      /1H ,5X,I7  ,6X      ,5X,15HINTERMEDIATE = ,  F13.4,       PM111900
     3           5X,0P2F10.3,9X           ,5X,0P3F10.5,                PM111910
     4      /1H ,5X,I7  ,6X      ,5X,15HMINOR        = ,  F13.4,       PM111920
     5           5X,0P2F10.3,9X           ,5X,0P3F10.5)                PM111930
 7700 DO 8000 J=1,3                                                     PM111940
      PSHAPE(J,I)=E(J)                                                  PM111950
      PTHETA(J,I)=THT(J)                                                PM111960
      PPHI  (J,I)=THT(J+3)                                              PM111970
 8000 CONTINUE                                                          PM111980
      PFF   (  I)=FF3                                                   PM111990
 9000 CONTINUE                                                          PM112000
      IF(IPL3) 9100,9100,9001                                           PM112010
 9001 DO 9080 J=1,3                                                     PM112020
      DATA CHK /75./                                                    PM112030
      SUM1=PTHETA(J,1)                                                  PM112040
      DO 9080 I=2,NCASE                                                 PM112050
      SUM2=PTHETA(J,I)                                                  PM112060
      IF(ABS(SUM2)-CHK) 9070,9010,9010                                  PM112070
 9010 IF(SUM1*SUM2) 9020,9070,9070                                      PM112080
 9020 PTHETA(J,I)=-SIGN(180.,SUM2)+SUM2                                 PM112090
 9070 SUM1=PTHETA(J,I)                                                  PM112100
 9080 CONTINUE                                                          PM112110
      CALL FPLTNG  (PSHAPE,PTHETA,PPHI   ,NCASE,LABEL1,LABEL2,         PM112120
     1              PFF   ,PYY   ,F3,THETA,NSKIP)                       PM112130
 9100 GO TO 1000                                                        PM112140
 9900 CALL FPLTNG  (PSHAPE,PTHETA,PPHI   ,NCASE,LABEL1,LABEL2,         PM112150
     1              PFF   ,PYY   ,F3,THETA,NSKIP)                       PM112160
      WRITE(6,9990)                                                     PM112170
 9990 FORMAT( 1H0,20X,24HJOB NORMALLY TERMINATED.)                      PM112180
      STOP                                                              PM112190
      END                                                               PM112200
```

```
      SUBROUTINE DSCTCN (DRLAT,DRLON,EPLAT,EPLON,THETA)                 DRCT   0
CC    RADIUS OF EARTH  (EQUIVALENT SPHERE)                              DRCT  10
      DATA RR/6371.2217/                                                DRCT  20
      DATA PAIA,PAIR/1.74532925E-2,57.29577951/                         DRCT  30
      DRLAT=DRLAT*PAIA                                                  DRCT  40
      DRLON=DRLON*PAIA                                                  DRCT  50
      EPLAT=EPLAT*PAIA                                                  DRCT  60
      EPLON=EPLON*PAIA                                                  DRCT  70
      AA   =EPLAT-DRLAT                                                 DRCT  80
      BB   =.5*(COS(EPLAT)+COS(DRLAT))*(EPLON-DRLON)                    DRCT  90
      THETA=-ATAN2(BB,AA)*PAIR                                          DRCT 100
      IF(THETA) 1100,1200,1200                                          DRCT 110
 1100 THETA=THETA+360.                                                  DRCT 120
 1200 DIST=RR*SQRT(AA*AA+BB*BB)                                         DRCT 130
      WRITE(6,2000) THETA,DIST                                          DRCT 140
 2000 FORMAT(/1H0,10X,33HSEISMOGRAPH STATION TO EPICENTER,              DRCT 150
     1       /1H0,20X,12HDIRECTION = ,F15.7, 9H (DEGREE),               DRCT 160
     2       /1H ,20X,12HDISTANCE  = ,F15.7,13H (KILO-METER))           DRCT 170
      RETURN                                                            DRCT 180
      END                                                               DRCT 190
```

```
      SUBROUTINE FFTR (A,ACOS,BSIN,N,IND,S,DT)                          FFTR   0
CC  FOURIER TRANSFORM, FOWARD TRANSFORM AND INVERSE TRANSFORM           FFTR  10
C  A      AR4  (N)        SAMPLES IN TIME-DOMAIN                       FFTR  20
C  ACOS   AR4  (N/2+1)    FOURIER COEFFICIENTS                         FFTR  30
C  BSIN   AR4  (N/2+1)    FOURIER COEFFICIENTS                         FFTR  40
C  N      I4               NUMBER OF F.F.T., SHOULD BE POWER OF 2.     FFTR  50
C  IND    I4               INDEX  =0.1   FOWARD TRANSFORM              FFTR  60
C                                 =0.2   INVERSE TRANSFORM             FFTR  70
C  S      AR4  (N/4-1)     WORKING AREA                                 FFTR  80
C  DT     R4               THE CONSTANT SAMPLING TIME INCREMENT        FFTR  90
      DIMENSION A(1),ACOS(1),BSIN(1),S(1)                               FFTR 100
      M=N/2                                                             FFTR 110
      MP1=M+1                                                           FFTR 120
      GO TO (1000,2000),IND                                             FFTR 130
CC  FOWARD TRANSFORMATION                                               FFTR 140
 1000 CALL FFT2 (A,ACOS,BSIN,N,S)                                       FFTR 150
      DO 1100 I=1,M                                                     FFTR 160
      ACOS(I)=ACOS(I)*DT                                                FFTR 170
 1100 BSIN(I)=BSIN(I)*DT                                                FFTR 180
      ACOS(MP1)=BSIN(1)                                                 FFTR 190
      BSIN(1)=0.                                                        FFTR 200
      BSIN(MP1)=0.                                                      FFTR 210
      RETURN                                                            FFTR 220
CC  INVERSE TRANSFORM                                                   FFTR 230
 2000 NP2=N+2                                                           FFTR 240
      XX=1./(FLOAT(N)*DT)                                               FFTR 250
      A(  1)=   ACOS(  1)*XX                                            FFTR 260
      A(MP1)=   ACOS(MP1)*XX                                            FFTR 270
      DO 2100 I=2,M                                                     FFTR 280
      J=NP2-I                                                           FFTR 290
      A(I)=   (ACOS(I)+BSIN(I))*XX                                      FFTR 300
 2100 A(J)=   (ACOS(I)-BSIN(I))*XX                                      FFTR 310
      CALL FFT2 (A,ACOS,BSIN,N,S)                                       FFTR 320
      A(  1)=ACOS(1)                                                    FFTR 330
      A(MP1)=BSIN(1)                                                    FFTR 340
      DO 2300 I=2,M                                                     FFTR 350
      J=NP2-I                                                           FFTR 360
      A(I)=ACOS(I)+BSIN(I)                                              FFTR 370
 2300 A(J)=ACOS(I)-BSIN(I)                                              FFTR 380
      RETURN                                                            FFTR 390
      END                                                               FFTR 400
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      SUBROUTINE FFT2(A,A1,B1,N,S)                                      FTR   0
C 189 D6/TC/FTR FAST FOURIER TRANSFORMATION                             FTR  10
      DIMENSION A(1),A1(1),B1(1),S(1)                                   FTR  20
      DATA  M/0 /                                                       FTR  30
      IF(N-8)  1000,5,5                                                 FTR  40
    5 IF(M-N)  10,30,10                                                 FTR  50
   10 M=N                                                               FTR  60
      N4=N/4-1                                                          FTR  70
      FLN=FLOAT(N)                                                      FTR  80
      DO  20  I=1,N4                                                    FTR  90
      S(I)=SIN(FLOAT(I)*6.2831853/FLN)                                  FTR 100
   20 CONTINUE                                                          FTR 110
   30 N1=N/2                                                            FTR 120
      IF(N.NE.N1*2)  GO TO 1200                                         FTR 130
      N11=N1/2                                                          FTR 140
      DO 100 I=1,N1                                                     FTR 150
      I1=I+N1                                                           FTR 160
      A1(I)=A(I)+A(I1)                                                  FTR 170
      B1(I)=A(I)-A(I1)                                                  FTR 180
  100 CONTINUE                                                          FTR 190
      DO 110 I=1,N1                                                     FTR 200
      I01=I+N1                                                          FTR 210
      A(I)=A1(I)                                                        FTR 220
      A(I01)=B1(I)                                                      FTR 230
  110 CONTINUE                                                          FTR 240
      N2=N1                                                             FTR 250
      DO 120 K=1,30                                                     FTR 260
      N21=N2/2                                                          FTR 270
      IF(N2.NE.N21*2)  GO TO 1200                                       FTR 280
      DO 130 I=1,N21                                                    FTR 290
      I1=I+N21                                                          FTR 300
      I2=I+N11                                                          FTR 310
      I01=I+N1                                                          FTR 320
      I11=I1+N1                                                         FTR 330
      A1(I)=A(I)+A(I1)                                                  FTR 340
      B1(I)=A(I)-A(I1)                                                  FTR 350
      A1(I2)=A(I01)                                                     FTR 360
      B1(I2)=A(I11)                                                     FTR 370
      IF(K.EQ.1) GO TO 130                                              FTR 380
      I3=I                                                              FTR 390
      I6=N1+I                                                           FTR 400
      JEND=N11-N21                                                      FTR 410
      DO 140 J=N21,JEND,N21                                             FTR 420
      I3=I3+N2                                                          FTR 430
      I31=I3+N1                                                         FTR 440
      I4=I3+N21                                                         FTR 450
      I41=I4+N1                                                         FTR 460
      I5=J+I                                                            FTR 470
      I6=I6-N21                                                         FTR 480
      J1=N11-J                                                          FTR 490
      APRIME=A(I4)*S(J1)-A(I41)*S(J)                                    FTR 500
      BPRIME=A(I41)*S(J1)+A(I4)*S(J)                                    FTR 510
      A1(I5)=A(I3)+APRIME                                               FTR 520
      B1(I5)=A(I31)+BPRIME                                              FTR 530
      A1(I6)=A(I3)-APRIME                                               FTR 540
      B1(I6)=-A(I31)+BPRIME                                             FTR 550
  140 CONTINUE                                                          FTR 560
  130 CONTINUE                                                          FTR 570
      IF(N21.EQ.1) RETURN                                               FTR 580
      DO 150 I=1,N1                                                     FTR 590
      I01=I+N1                                                          FTR 600
      A(I)=A1(I)                                                        FTR 610
      A(I01)=B1(I)                                                      FTR 620
  150 CONTINUE                                                          FTR 630
      N2=N21                                                            FTR 640
  120 CONTINUE                                                          FTR 650
      RETURN                                                            FTR 660
 1000 WRITE(6,1100)                                                     FTR 670
 1100 FORMAT(15H (SUBR. FFT    ) / 24H N MUST BE LARGER THAN 7 )        FTR 680
      RETURN                                                            FTR 690
 1200 WRITE(6,1300)                                                     FTR 700
 1300 FORMAT(15H (SUBR. FFT    )/33H N MUST BE A POSITIVE POWER OF 2 )  FTR 710
      RETURN                                                            FTR 720
      END                                                               FTR 730
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      SUBROUTINE SHB1(G,N,E,V,NEV,NVEC,IND,ITRI,H,P,NL)                 SHB1   0
C                                                                       SHB1  10
C                                                                       SHB1  20
C 196 F2/TC/SHB1                                                        SHB1  30
CC                                                                      SHB1  40
C                                                                       SHB1  50
C PURPOSE                                                               SHB1  60
C     CALCULATION OF EIGENVALUES AND EIGENVECTORS OF A REAL AND         SHB1  70
C     SYMMETRIC MATRIX.                                                 SHB1  80
C                                                                       SHB1  90
C USAGE                                                                 SHB1 100
C     CALL SHB1(G,N,E,V,NEV,NVEC,IND,ITRI,H,P,NL)                       SHB1 110
C                                                                       SHB1 120
C DESCRIPTION OF THE PARAMETERS                                         SHB1 130
C     G   THE INPUT REAL SYMMETRIC MATRIX,ARRAY(NL,NL)                  SHB1 140
C     NL  DIMENSION SIZE OF MAIN PROGAM MATRIX                          SHB1 150
C     N   THE DIMENSION OF DATA MATRIX                                  SHB1 160
C     E   THE EIGENVALUES ARE CONTAINED ON RETURN. ARRAY(NVEC), REAL    SHB1 170
C     V   THE EIGENVECTORS ARE STORED ON RETURN. I-TH COLUMN OF V       SHB1 180
C         CORRESPONS TO I-TH EIGENVALUE. ARRAY(NL,NVEC). REAL           SHB1 190
C     NVEC IF NVEC=0,ONLY EIGENVALUES ARE COMPUTED. OTHERWISE NVEC      SHB1 200
C         EIGENVECTORS ARE COMPUTED.                                    SHB1 210
C     IND IF IND=1, NEV ALGEBRAICALLY LARGEST EIGENVALUES ARE COMPUTED. SHB1 220
C         IF IND=2, NEV ALGEBRAICALLY SMALLEST EIGENVALUES ARE COMPUTED.SHB1 230
C         INTEGER                                                       SHB1 240
C     ITRI IF INPUT MATRIX IS NOT TRI-DIAGONAL ITRI=1                   SHB1 250
C         IF INPUT MATRIX IS TRI-DIAGONAL ITRI=2                        SHB1 260
C     H   H(I,1),I=1,...,N  DIAGONAL ELEMENTS OF TRI-DIAGONALIZED       SHB1 270
C         MATRIX ON RETURN.                                             SHB1 280
C         H(I,2),I=1,...,N-1 CO-DIAGONAL ELEMENTS OF TRI-DIAGONALIZED   SHB1 290
C         MATRIX ON RETURN.                                             SHB1 300
C         ARRAY H(NL,2),REAL                                            SHB1 310
C     P   WARKING STORAGE ARRAY P(N,5), REAL                            SHB1 320
C                                                                       SHB1 330
C REMARKS                                                               SHB1 340
C     THE ORIGINAL MATRIX IS DESTROYED.                                 SHB1 350
C     NVEC MUST NOT EXCEED NEV                                          SHB1 360
C     IF INPUT ORIGINAL MATRIX IS TRI-DIAGONAL,STORE THE DIAGONAL       SHB1 370
C     ELEMENTS IN H(I,1),I=1,...,N, AND THE CO-DIAGONAL ELEMENTS IN     SHB1 380
C     H(2,2),I=1,...,N-1, AND SET ITRI=2 WHEN CALLING THIS SUBROUTINE,  SHB1 390
C     IN THIS CASE ARRAY G IS 1 BY 1 IN CALLING PROGRAM.                SHB1 400
C SUBROUTINE AND FUNCTION SUBPROGRAMS REQUIRED                          SHB1 410
C                                                                       SHB1 420
C     NONE                                                              SHB1 430
C                                                                       SHB1 440
C METHOD                                                                SHB1 450
C     REDUCE A MATRIX TO TRIDIAGONAL FORM BY HOUSEHOLDERS               SHB1 460
C     COMPUTE EIGENVALUES BY BISECTION METHOD.                          SHB1 470
C     COMPUTE EIGENVECTORS BY INVERSE ITERATION.                        SHB1 480
C     RALSTON AND WILF,MATHEMATICAL METHODS FOR DIGITAL COMPUTERS,VOL2, SHB1 490
C      1968 PP 94-159.                                                  SHB1 500
C                                                                       SHB1 510
C                                                                       SHB1 520
      DIMENSION G(NL,NL),E(NL),V(NL,NL),H(NL,2),P(NL,5)                 SHB1 530
      REAL L                                                            SHB1 540
      LOGICAL FIRST                                                     SHB1 550
      IF ((NL-N).LT.0) RETURN                                           SHB1 560
      IF(N.LE.1) RETURN                                                 SHB1 570
C  TRI-DIAGONALIZATION OF GIVEN MATRIX BY HOUSEHOLDER'S METHOD          SHB1 580
      EPSS=1.0E-24                                                      SHB1 590
      NM1=N-1                                                           SHB1 600
      GO TO (100,200),ITRI                                              SHB1 610
  100 IF(N.EQ.2) GO TO 9                                                SHB1 620
      NM2=N-2                                                           SHB1 630
      DO 8 I=1,NM2                                                      SHB1 640
      IP1=I+1                                                           SHB1 650
      SS=0.                                                             SHB1 660
      GK=G(IP1,I)                                                       SHB1 670
      DO 1 J=IP1,N                                                      SHB1 680
    1 SS=SS+G(J,I)*G(J,I)                                               SHB1 690
      IF(SS.LT.EPSS) GO TO 89                                           SHB1 700
      S= SQRT(SS)                                                       SHB1 710
      IF(GK.LT.0.0) S=-S                                                SHB1 720
      H(I,1)=G(I,I)                                                     SHB1 730
      H(I,2)=-S                                                         SHB1 740
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      TT=0.                                                          SHB1 750
      TT=1.0E+0/(SS+GK*S)                                            SHB1 760
      T=GK+S                                                         SHB1 770
      G(IP1,I)=T                                                     SHB1 780
      P(IP1,3)=T                                                     SHB1 790
      IP2=I+2                                                        SHB1 800
      DO 2 J=IP2,N                                                   SHB1 810
    2 P(J,3)=G(J,I)                                                  SHB1 820
      DO 4 J=IP1,N                                                   SHB1 830
      T=0.0                                                          SHB1 840
      DO 3 K=IP1,N                                                   SHB1 850
    3 T=T+G(K,J)*P(K,3)                                              SHB1 860
    4 P(J,1)=T*TT                                                    SHB1 870
      SS=0.                                                          SHB1 880
      DO 5 K=IP1,N                                                   SHB1 890
    5 SS=SS+P(K,3)*P(K,1)                                            SHB1 900
      SS=0.5E+0*SS*TT                                                SHB1 910
      DO 6 K=IP1,N                                                   SHB1 920
    6 P(K,2)=P(K,1)-SS*P(K,3)                                        SHB1 930
      DO 7 J=IP1,N                                                   SHB1 940
      DO 7 K=J,N                                                     SHB1 950
      G(K,J)=G(K,J)-(P(J,2)*P(K,3)+P(K,2)*P(J,3))                    SHB1 960
    7 G(J,K)=G(K,J)                                                  SHB1 970
      GO TO 8                                                        SHB1 980
   89 TT=0.0E0                                                       SHB1 990
      H(I,1)=G(I,I)                                                  SHB11000
      H(I,2)=0.0E0                                                   SHB11010
    8 G(I,I)=TT                                                      SHB11020
    9 H(NM1,1)=G(NM1,NM1)                                            SHB11030
      H(NM1,2)=G(NM1,N)                                              SHB11040
      H(N,1)=G(N,N)                                                  SHB11050
      H(N,2)=0.                                                      SHB11060
  200 CONTINUE                                                       SHB11070
C   CALCULATION OF EIGENVALUES OF TRANSFORMED MATRIX BY BINARY CHOPPING SHB11080
      TT=ABS(H(1,1))+ABS(H(1,2))                                     SHB11090
      DO 10 I=2,N                                                    SHB11100
      S=ABS(H(I,1))+ABS(H(I,2))+ABS(H(I-1,2))                        SHB11110
C  10 TT=MAX1(TT,S)                                                  SHB11120
   10 TT=AMAX1(TT,S)                                                 SHB11130
      DO 11 I=1,N                                                    SHB11140
   11 P(I,3)=H(I,2)*P(I,2)                                           SHB11150
      ZERO=1.0E-38                                                   SHB11160
      K=1                                                            SHB11170
      IF(IND.EQ.2) TT=-TT                                            SHB11180
      U=TT                                                           SHB11190
      DO 12 I=1,NEV                                                  SHB11200
   12 E(I)=-TT                                                       SHB11210
   13 L=E(K)                                                         SHB11220
      EPS=1.0E-7*ABS(U)                                              SHB11230
   14 T=0.5E+0*(L+U)                                                 SHB11240
      IF((ABS(U-T).LE.EPS ).OR.(ABS(T-L).LE.EPS)) GO TO 30           SHB11250
      J=0                                                            SHB11260
      I=1                                                            SHB11270
   16 S=H(I,1)-T                                                     SHB11280
   19 IF(S.GE.-ZERO) J=J+1                                           SHB11290
      IF(ABS(S).LE.ZERO) GO TO 20                                    SHB11300
      I=I+1                                                          SHB11310
      IF(I.GT.N) GO TO 21                                            SHB11320
      S=H(I,1)-T-P(I-1,3)/S                                          SHB11330
      GO TO 19                                                       SHB11340
   20 I=I+2                                                          SHB11350
      IF (I.LE.N) GO TO 16                                           SHB11360
   21 GO TO (23,22), IND                                             SHB11370
   22 J=N-J                                                          SHB11380
   23 IF(J.GE.K) GO TO 24                                            SHB11390
      U=T                                                            SHB11400
      GO TO 14                                                       SHB11410
   24 L=T                                                            SHB11420
      M=MIN0(J,NEV)                                                  SHB11430
      DO 26 I=K,M                                                    SHB11440
   26 E(I)=T                                                         SHB11450
      GO TO 14                                                       SHB11460
   30 E(K)=T                                                         SHB11470
      K=K+1                                                          SHB11480
      IF(K.LE.NEV) GO TO 13                                          SHB11490
      IF(NVEC.EQ.0) RETURN                                           SHB11500
C CALCULATION OF EIGENVECTORS BY WIELANDT'S INVERSE ITERATION        SHB11510
C     IR=1234567                                                     SHB11520
      DO 600 I=1,NVEC                                                SHB11530
      DO 44 J=1,N                                                    SHB11540
      P(J,1)=0.                                                      SHB11550
      P(J,2)=H(J,2)                                                  SHB11560
      P(J,3)=H(J,1)-E(I)                                             SHB11570
   44 V(J,I)=1.0E+0                                                  SHB11580
      FIRST=.TRUE.                                                   SHB11590
      DO 50 J=1,NM1                                                  SHB11600
      PJ3=P(J,3)                                                     SHB11610
      HJ1=H(J,2)                                                     SHB11620
      IF(ABS(PJ3).LT.ABS(HJ1)) GO TO 46                              SHB11630
      SS=HJ1/PJ3                                                     SHB11640
      P(J,4)=0.                                                      SHB11650
      GO TO 48                                                       SHB11660
   46 SS=PJ3/HJ1                                                     SHB11670
      P(J,4)=1.0E+0                                                  SHB11680
      P(J,3)=H(J,2)                                                  SHB11690
      T=P(J+1,3)                                                     SHB11700
      P(J+1,3)=P(J,2)                                                SHB11710
      P(J,2)=T                                                       SHB11720
      P(J,1)=P(J+1,2)                                                SHB11730
      P(J+1,2)=0.                                                    SHB11740
   48 P(J,5)=SS                                                      SHB11750
      P(J+1,2)=P(J+1,2)-SS*P(J,1)                                    SHB11760
      P(J+1,3)=P(J+1,3)-SS*P(J,2)                                    SHB11770
C     IF (P(J,3).EQ.0.)  P(J,3)=1.0E-30                              SHB11780
      IF (P(J,3).EQ.0.)  P(J,3)=1.0E-30                              SHB11790
   50 CONTINUE                                                       SHB11800
      IF(P(N,3).EQ.0.) P(N,3)=1.0E-30                                SHB11810
      IF(I.EQ.1.OR.ABS(E(I)-E(I-1)).GE.TT*1.0E-6) GO TO 54           SHB11820
      DO 52 J=1,N                                                    SHB11830
C     IR=IR*48828125                                                 SHB11840
C  52 V(J,I)=FLOAT(IR)*0.4656613E-9                                  SHB11850
   52 V(J,I)=RANF(0.0)                                               SHB11860
C  54 CALL OVERFL(II)                                                SHB11870
   54 CONTINUE                                                       SHB11880
      DO 66 J=1,N                                                    SHB11890
      K=N-J+1                                                        SHB11900
      T=V(K,I)                                                       SHB11910
   62 S=0.                                                           SHB11920
      SS=0.                                                          SHB11930
      IF(K.LT.N) S=V(K+1,I)                                          SHB11940
      IF(K.LT.NM1) SS=V(K+2,I)                                       SHB11950
      V(K,I)=(T-S*P(K,2)-SS*P(K,1))/P(K,3)                           SHB11960
      CALL OVERFL(II)                                                SHB11970
CC    II=LEGVAR(V(K,I))                                              SHB11980
      IF(II.NE.1) GO TO 66                                           SHB11990
      DO 64 M=1,N                                                    SHB12000
   64 V(M,I)=V(M,I)*1.0E-5                                           SHB12010
      T=T*1.0E-5                                                     SHB12020
      GO TO 62                                                       SHB12030
   66 CONTINUE                                                       SHB12040
      IF (.NOT.FIRST) GO TO 74                                       SHB12050
      FIRST=.FALSE.                                                  SHB12060
      DO 70 J=1,NM1                                                  SHB12070
      JP1=J+1                                                        SHB12080
      IF(P(J,4).NE.0.0) GO TO 68                                     SHB12090
      V(JP1,I)=V(JP1,I)-P(J,5)*V(J,I)                                SHB12100
      GO TO 70                                                       SHB12110
   68 T=V(J,I)                                                       SHB12120
      V(J,I)=V(JP1,I)                                                SHB12130
      V(JP1,I)=T-P(J,5)*V(JP1,I)                                     SHB12140
   70 CONTINUE                                                       SHB12150
      GO TO 54                                                       SHB12160
   74 GO TO (400,500),IYRI                                           SHB12170
  400 IF(N.EQ.2) GO TO 500                                           SHB12180
      DO 78 J=1,NM2                                                  SHB12190
      T=0.                                                           SHB12200
      K=N-J-1                                                        SHB12210
      M=K+1                                                          SHB12220
      DO 76 KK=M,N                                                   SHB12230
   76 T=T+G(KK,K)*V(KK,I)                                            SHB12240
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      T=T*G(K,K)                                                    SHB12250
      DO 78 KK=M,N                                                  SHB12260
   78 V(KK,I)=V(KK,I)-T*G(KK,K)                                     SHB12270
  500 T=0.                                                          SHB12280
      DO 80 J=1,N                                                   SHB12290
      SS=ABS(V(J,I))                                                SHB12300
   80 IF(SS.GT.T) T=SS                                              SHB12310
      DO 81 J=1,N                                                   SHB12320
   81 V(J,I)=V(J,I)/T                                               SHB12330
      T=0.                                                          SHB12340
      DO 82 J=1,N                                                   SHB12350
   82 T=T+V(J,I)*V(J,I)                                             SHB12360
      T=SQRT(T)                                                     SHB12370
      DO 600 J=1,N                                                  SHB12380
  600 V(J,I)=V(J,I)/T                                               SHB12390
      RETURN                                                        SHB12400
      END                                                           SHB12410
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      SUBROUTINE  FPLTNG (PS,PT,PP,NCASE,LINE1,LINE2,               FPLT   0
     1                    XX,YY,XEND,THT,INDEX)                     FPLT  10
      DIMENSION PS(3, 1),PT(3, 1),PP(3, 1),XX( 1),YY( 1),          FPLT  20
     1          LINE1(1),LINE2(1)                                   FPLT  30
      DIMENSION GIVEN(5),SPECS(30)                                  FPLT  40
      DIMENSION XX2(2),YY2(2)                                       FPLT  50
      REAL MAX                                                      FPLT  60
      IF(INDEX.EQ.999) GO TO 9000                                   FPLT  70
      I=IFIX(XEND/5.+ .99 )                                         FPLT  80
      XX3=FLOAT(I)*5.                                               FPLT  90
      LINE1(5)=0                                                    FPLT 100
      LINE2(7)=0                                                    FPLT 110
      MAX=0.                                                        FPLT 120
      DO 1200 I=1,NCASE                                             FPLT 130
      IF(MAX-PS(1,I)) 1100,1200,1200                                FPLT 140
 1100 MAX=PS(1,I)                                                   FPLT 150
 1200 CONTINUE                                                      FPLT 160
C  TO DETERMINE LAYOUT OF Y-AXIS SCALE                             FPLT 170
      GIVEN(1)=MAX                                                  FPLT 180
      GIVEN(2)=0.                                                   FPLT 190
      GIVEN(3)=3.                                                   FPLT 200
      GIVEN(4)=2.                                                   FPLT 210
      GIVEN(5)=1.                                                   FPLT 220
          CALL FAGLIY (GIVEN,SPECS)                                 FPLT 230
      DM 5=SPECS( 5)                                                FPLT 240
      DM 6=SPECS( 6)                                                FPLT 250
      DM 8=SPECS( 8)                                                FPLT 260
      DM10=SPECS(10)                                                FPLT 270
      GIVEN(3)=4.                                                   FPLT 280
          CALL FAGLIY (GIVEN,SPECS)                                 FPLT 290
      IF(SPECS( 8).GE.DM 8) GO TO 1500                              FPLT 300
       SPECS( 5)=DM 5                                               FPLT 310
       SPECS( 6)=DM 6                                               FPLT 320
       SPECS( 8)=DM 8                                               FPLT 330
       SPECS(10)=DM10                                               FPLT 340
 1500 GIVEN(3)=5.                                                   FPLT 350
      DM 5=SPECS( 5)                                                FPLT 360
      DM 6=SPECS( 6)                                                FPLT 370
      DM 8=SPECS( 8)                                                FPLT 380
      DM10=SPECS(10)                                                FPLT 390
          CALL FAGLIY (GIVEN,SPECS)                                 FPLT 400
      IF(SPECS( 8).GT.DM 8) GO TO 1600                              FPLT 410
       SPECS( 5)=DM 5                                               FPLT 420
       SPECS( 6)=DM 6                                               FPLT 430
       SPECS( 8)=DM 8                                               FPLT 440
       SPECS(10)=DM10                                               FPLT 450
 1600 CONTINUE                                                      FPLT 460
       SPECS( 1)=1.                                                 FPLT 470
       SPECS( 2)=1.                                                 FPLT 480
      XL = .625                                                     FPLT 490
       SPECS( 7)=XX3*XL                                             FPLT 500
       SPECS( 9)=XX3/5.+.001                                        FPLT 510
       SPECS(11)=1.                                                 FPLT 520
       SPECS(12)=99.                                                FPLT 530
C  RECTANGULAR GRID PLOTTING FOR SHAPE FUNCTION                    FPLT 540
          CALL GDLILI (SPECS)                                       FPLT 550
       SPECS( 9)=(XX3+ .001)*2.                                     FPLT 560
          CALL AXLILI (SPECS)                                       FPLT 570
       SPECS( 3)=XX3                                                FPLT 580
       SPECS( 4)=0.                                                 FPLT 590
       SPECS( 9)=XX3/2.5+ .001                                      FPLT 600
       SPECS(17)= .15                                               FPLT 610
       SPECS(18)= .15                                               FPLT 620
       SPECS(19)=0.                                                 FPLT 630
       SPECS(21)=1.                                                 FPLT 640
       SPECS(24)= .1                                                FPLT 650
       SPECS(28)=1.                                                 FPLT 660
          CALL NODLIB (SPECS)                                       FPLT 670
       SPECS(20)=0.                                                 FPLT 680
       SPECS(26)= .1                                                FPLT 690
          CALL NODLIL (SPECS)                                       FPLT 700
       SPECS(13)=FLOAT(NCASE)+ .001                                 FPLT 710
       SPECS(14)=1.                                                 FPLT 720
       SPECS(15)=1.                                                 FPLT 730
C  PLOT SHAPE FUNCTION                                             FPLT 740
      DO 2200 J=1,3                                                 FPLT 750
      DO 2100 I=1,NCASE                                             FPLT 760
 2100 YY(I)=PS(J,I)                                                 FPLT 770
 2200     CALL PLT2 (J,SPECS,XX,YY)                                 FPLT 780
       SPECS(17)= .18                                               FPLT 790
       SPECS(18)= .18                                               FPLT 800
          CALL TITLEB (12HHZ (1./SEC.),SPECS)                       FPLT 810
          CALL TITLEL ( 8HSIGMA      ,SPECS)                        FPLT 820
C  RECTANGULAR GRID PLOTTING FOR THETA                             FPLT 830
       SPECS( 2)=3.5                                                FPLT 840
       SPECS( 8)=1.8                                                FPLT 850
       SPECS( 9)=XX3/5.+ .001                                       FPLT 860
       SPECS(10)=4.                                                 FPLT 870
          CALL GDLILI (SPECS)                                       FPLT 880
       SPECS(10)=12.                                                FPLT 890
          CALL AXLILI (SPECS)                                       FPLT 900
       SPECS( 5)= 90.                                               FPLT 910
       SPECS( 6)=-90.                                               FPLT 920
       SPECS(10)=4.                                                 FPLT 930
       SPECS(17)= .15                                               FPLT 940
       SPECS(18)= .15                                               FPLT 950
       SPECS(26)= .1                                                FPLT 960
       SPECS(28)=  0.                                               FPLT 970
          CALL NODLIL (SPECS)                                       FPLT 980
C  PLOT (THETA)                                                    FPLT 990
      DO 3150 J=1,3                                                 FPLT1000
      DO 3100 I=1,NCASE                                             FPLT1010
 3100 YY(I)=PT(J,I)                                                 FPLT1020
 3150     CALL PLT2 (J,SPECS,XX,YY)                                 FPLT1030
      THETA=THT                                                     FPLT1040
 3200 IF(THETA.LE.-90.) THETA=THETA+180.                            FPLT1050
      IF(THETA.GT. 90.) THETA=THETA-180.                            FPLT1060
      IF((THETA.LE.-90.).OR.(THETA.GT. 90.)) GO TO 3200             FPLT1070
      XX2(1)=XX3                                                    FPLT1080
      XX2(2)=0.                                                     FPLT1090
      YY2(1)=THETA                                                  FPLT1100
      YY2(2)=THETA                                                  FPLT1110
      DASH= .2                                                      FPLT1120
      SPACE= .1                                                     FPLT1130
       SPECS(13)=2.001                                              FPLT1140
          CALL DLLILI (XX2,YY2,DASH,SPACE,SPECS)                    FPLT1150
       SPECS(17)= .18                                               FPLT1160
       SPECS(18)= .18                                               FPLT1170
          CALL TITLEL (5HTHETA,SPECS)                               FPLT1180
C  RECTANGULAR GRID PLOTTING FOR PHI                               FPLT1190
       SPECS( 2)=5.7                                                FPLT1200
       SPECS( 8)= .9                                                FPLT1210
       SPECS(10)=3.                                                 FPLT1220
          CALL GDLILI (SPECS)                                       FPLT1230
       SPECS(10)= 9.                                                FPLT1240
          CALL AXLILI (SPECS)                                       FPLT1250
       SPECS( 5)=90.                                                FPLT1260
       SPECS( 6)= 0.                                                FPLT1270
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      SPECS(10)=3.                                                    FPLT1280
      SPECS(17)= .15                                                  FPLT1290
      SPECS(18)= .15                                                  FPLT1300
      SPECS(26)= .1                                                   FPLT1310
         CALL NODL1L (SPECS)                                          FPLT1320
C  PLOT (PHI)                                                         FPLT1330
      SPECS(13)=FLOAT(NCASE)+ .001                                    FPLT1340
      DO 4200 J=1,2                                                   FPLT1350
      DO 4100 I=1,NCASE                                               FPLT1360
 4100 YY(I)=PP(J,I)                                                   FPLT1370
 4200    CALL PLT2 (J,SPECS,XX,YY)                                    FPLT1380
      SPECS(17)= .18                                                  FPLT1390
      SPECS(18)= .18                                                  FPLT1400
         CALL TITLEL (3HPHI,SPECS)                                    FPLT1410
      SPECS( 9)=(XX3+ .001)*2.                                        FPLT1420
      SPECS(25)= .0                                                   FPLT1430
         CALL SAXLIT (SPECS)                                          FPLT1440
      SPECS( 9)=XX3/2.5+ .001                                         FPLT1450
      SPECS(17)= .15                                                  FPLT1460
      SPECS(18)= .15                                                  FPLT1470
      SPECS(25)= .2                                                   FPLT1480
      SPECS(28)=1.                                                    FPLT1490
         CALL NODLIT (SPECS)                                          FPLT1500
      SPECS(22)=1.                                                    FPLT1510
      SPECS(23)=7.4                                                   FPLT1520
      RULE=1.                                                         FPLT1530
         CALL TITLEG (RULE,LINE2,SPECS)                               FPLT1540
      SPECS(17)= .18                                                  FPLT1550
      SPECS(18)= .18                                                  FPLT1560
      SPECS(23)=7.7                                                   FPLT1570
         CALL TITLEG (RULE,LINE1,SPECS)                               FPLT1580
         CALL NXTFRM (SPECS)                                          FPLT1590
      RETURN                                                          FPLT1600
 9000 WRITE(6,9100)                                                   FPLT1610
 9100 FORMAT(1H0,20X,19HPLOTTER TERMINATED.)                          FPLT1620
      SPECS(12)=99.                                                   FPLT1630
         CALL GOSEND (SPECS)                                          FPLT1640
      RETURN                                                          FPLT1650
      END                                                             FPLT1660
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         SUBROUTINE PLT2 (I,S,XX,YY)                                  PLT    0
         DIMENSION S(1),XX(1),YY(1)                                   PLT   10
      GO TO (1000,2000,3000),I                                        PLT   20
 1000    CALL SLLILI (XX,YY,S)                                        PLT   30
      GO TO 5000                                                      PLT   40
 2000 DASH = .1                                                       PLT   50
      GO TO 4000                                                      PLT   60
 3000 DASH = .04                                                      PLT   70
 4000 SPACE= .05                                                      PLT   80
         CALL DLLILI (XX,YY,DASH,SPACE,S)                             PLT   90
 5000 RETURN                                                          PLT  100
      END                                                             PLT  110
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      PROGRAM PGM21  (INPUT,OUTPUT,7U538,                                -PM21   0
     1                TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=PUNCH,             PM21  10
     2                TAPE1,TAPE99)                                     PM21  20
COMMENT       MOVING FOURIER PROGRAM                                    PM21  30
COMMENT       SUBROUTINES, REQUIRED                                     PM21  40
C   SUBROUTINE SHB1                                                     PM21  50
C   SUBROUTINE FFTR                                                     PM21  60
C   SUBROUTINE HANNG                                                    PM21  70
C   SUBROUTINE LEVEL                                                    PM21  80
C   SUBROUTINE OUTPUT                                                   PM21  90
      DIMENSION CORTIL(200),ICOR(100),FCOR(100)                         PM21 100
      DIMENSION DATA(3,1500)                                            PM21 110
      DIMENSION WORK( 256),ACOS1( 129),BSIN1( 129),S( 63)               PM21 120
      DIMENSION CNTOUR(3,52,51),YY(52),TT(51),BUFFER(750)               PM21 130
      DIMENSION ACC(3, 250)                                             PM21 140
      DIMENSION G(3,3),E(3),V(3,3),H(3,2),P(3,5)          ,COMP(3)      PM21 150
      DIMENSION LABEL1(5),LABEL2(7)                                     PM21 160
      DIMENSION ZAREA(51,52)                                            PM21 170
      INTEGER CORTIL                                                    PM21 180
      EQUIVALENCE (ACC(   1),CORTIL(1)),(ACC( 201),ICOR(1)),            PM21 190
     1            (ACC( 301),FCOR(1))                                   PM21 200
      EQUIVALENCE (CNTOUR(3051),DATA(1))                                PM21 210
      EQUIVALENCE (ACC(1),BUFFER(1))                                    PM21 220
      EQUIVALENCE (ZAREA(1),WORK(1)),(ZAREA(1025),ACOS1(1)),            PM21 230
     1            (ZAREA(1538),BSIN1(1)),(ZAREA(2051),S(1))             PM21 240
      CALL SETFXB (1.2500,100)                                          PM21 250
CC                                                                      PM21 260
CC  T1   =  TIME LENGTH OF WINDOW                                       PM21 270
CC  T2   =  TIME, SKIPPED                                               PM21 280
CC  T3   =  TERMINATE LENGTH OF TIME                                    PM21 290
CC                                                                      PM21 300
 1000 READ(5,101) NSKIP,T1,T2,T3,NFFT,ISMTH                             PM21 310
      IF(NSKIP.EQ.999) GO TO 9900                                       PM21 320
CC                                                                      PM21 330
  101 FORMAT(I8,3F8.0,6I8)                                              PM21 340
  102 FORMAT( 8A10)                                                     PM21 350
  111 FORMAT(10I10)                                                     PM21 360
  113 FORMAT(10F10.1)                                                   PM21 370
CC     READING MAGNETIC FILESETS                                        PM21 380
      IF(NSKIP.EQ.0) GO TO 1200                                         PM21 390
      NSKIP=3*NSKIP                                                     PM21 400
          CALL SKIPF (5LTAPE1,NSKIP,3HEOF)                              PM21 410
 1200 WRITE(6,200)                                                      PM21 420
      DO 2000 J=1,3                                                     PM21 430
      READ(1,102) CORTIL                                                PM21 440
      IF(EOF,1) 1300,1400                                               PM21 450
 1300 READ(1,102) CORTIL                                                PM21 460
 1400 WRITE(6,210) J,(CORTIL(I),I=1,8),(CORTIL(I),I=41,56),             PM21 470
     1             (CORTIL(I),I=169,176)                                PM21 480
      READ(1,111) ICOR                                                  PM21 490
      COMP(J)=FLOAT(ICOR(27))                                           PM21 500
      KAZU=ICOR(53)                                                     PM21 510
      READ(1,113) FCOR                                                  PM21 520
      IF(KAZU.GT.1500) KAZU=1500                                        PM21 530
      READ(1,113) (DATA(J,I),I=1,KAZU)                                  PM21 540
          CALL SKIPF (5LTAPE1,    1,3HEOF)                              PM21 550
 2000 CONTINUE                                                          PM21 560
      DO 2100 I=1,4                                                     PM21 570
 2100 LABEL1(I)=CORTIL(I+40)                                            PM21 580
      DO 2110 I=1,6                                                     PM21 590
 2110 LABEL2(I)=CORTIL(I+48)                                            PM21 600
CC                                                                      PM21 610
  200 FORMAT(1H1)                                                       PM21 620
  210 FORMAT(1H0     ,13HRECORD NO. = ,I2,   /1H ,5X,8A10,              PM21 630
     1          /1H , 5X,8A10,/1H , 5X,8A10,/1H , 5X,8A10)             PM21 640
      WRITE(6,3050) T1,T2,T3                                            PM21 650
 3050 FORMAT(/1H0,25HTIME LENGTH OF WINDOW  = ,F15.7,7H (SEC.),         PM21 660
     1       /1H ,25HTIME INTERVAL, SKIPPED = ,F15.7,7H (SEC.),         PM21 670
     2       /1H ,25HTERMINATE LENGTH       = ,F15.7,7H (SEC.))        PM21 680
      WRITE(6,3100) ISMTH                                               PM21 690
 3100 FORMAT(/1H0,31HNUMBER OF CYCLE OF SMOOTHING = ,I8)                PM21 700
      IND1=1                                                            PM21 710
      IF((COMP(1).GT.COMP(2)).AND.(COMP(1)-COMP(2).LT. 90.1)) IND1=2    PM21 720
      IF((COMP(2).GT.COMP(1)).AND.(COMP(2)-COMP(1).GT.269.9)) IND1=2    PM21 730
      IND2=1                                                            PM21 740
      IF(COMP(3).EQ.500.) IND2=2                                        PM21 750
      IF(COMP(3).EQ.600.) IND2=3                                        PM21 760
      IF(IND2.EQ.1) WRITE(6,3300)                                       PM21 770
 3300 FORMAT( 1H ,40H***** VERTICAL COMPONENT = (VERT.) *****)          PM21 780
      NCASE=(T3-   T1)/T2+1.001                                         PM21 790
      DO 6900 I=1,NCASE                                                 PM21 800
      N1= FLOAT(I-1)* T2      /.02+1.001                                PM21 810
      N2=(FLOAT(I-1)* T2+ T1)/.02+ .001                                 PM21 820
      MN1=-N1+1                                                         PM21 830
      KAZU=N2+MN1                                                       PM21 840
      GO TO (4100,4200),IND1                                            PM21 850
 4100 I1=2                                                              PM21 860
      I2=1                                                              PM21 870
      GO TO 4300                                                        PM21 880
 4200 I1=1                                                              PM21 890
      I2=2                                                              PM21 900
 4300 DO 4400 J=N1,N2                                                   PM21 910
      K=J+MN1                                                           PM21 920
      ACC(1,K)=-DATA(I1,J)                                              PM21 930
 4400 ACC(2,K)=-DATA(I2,J)                                              PM21 940
      GO TO (4700,4600,4700),IND2                                       PM21 950
 4600 DO 4650 J=N1,N2                                                   PM21 960
      K=J+MN1                                                           PM21 970
 4650 ACC( 3,K)=-DATA(3,J)                                              PM21 980
      GO TO 4800                                                        PM21 990
 4700 DO 4750 J=N1,N2                                                   PM211000
      K=J+MN1                                                           PM211010
 4750 ACC( 3,K)= DATA(3,J)                                              PM211020
 4800 CONTINUE                                                          PM211030
      SUM1=0.                                                           PM211040
      SUM2=0.                                                           PM211050
      SUM3=0.                                                           PM211060
      SUM4=0.                                                           PM211070
      SUM5=0.                                                           PM211080
      SUM6=0.                                                           PM211090
      DO 5100 J=1,KAZU                                                  PM211100
      XX1=ACC(1,J)                                                      PM211110
      XX2=ACC(2,J)                                                      PM211120
      XX3=ACC(3,J)                                                      PM211130
      SUM1=SUM1+XX1*XX1                                                 PM211140
      SUM2=SUM2+XX1*XX2                                                 PM211150
      SUM3=SUM3+XX1*XX3                                                 PM211160
      SUM4=SUM4+XX2*XX2                                                 PM211170
      SUM5=SUM5+XX2*XX3                                                 PM211180
 5100 SUM6=SUM6+XX3*XX3                                                 PM211190
      XX=1./FLOAT(KAZU)                                                 PM211200
      G(1,1)=SUM1*XX                                                    PM211210
      G(2,1)=SUM2*XX                                                    PM211220
      G(3,1)=SUM3*XX                                                    PM211230
      G(1,2)=SUM2*XX                                                    PM211240
      G(2,2)=SUM4*XX                                                    PM211250
      G(3,2)=SUM5*XX                                                    PM211260
      G(1,3)=SUM3*XX                                                    PM211270
      G(2,3)=SUM5*XX                                                    PM211280
      G(3,3)=SUM6*XX                                                    PM211290
      TT(I)=FLOAT(N2+N1-1)* .01                                         PM211300
CC                                                                      PM211310
          CALL SHB1 (G,3,E,V,3,3,1,1,H,P,3)                             PM211320
CC                                                                      PM211330
COMMENT  ACCELEROGRAMS, CORRELATED TO PRINCIPAL AXES                    PM211340
      DO 5500 J=1,KAZU                                                  PM211350
      XX1=ACC(1,J)                                                      PM211360
      XX2=ACC(2,J)                                                      PM211370
      XX3=ACC(3,J)                                                      PM211380
      ACC(1,J)=XX1*V(1,1)+XX2*V(2,1)+XX3*V(3,1)                         PM211390
      ACC(2,J)=XX1*V(1,2)+XX2*V(2,2)+XX3*V(3,2)                         PM211400
 5500 ACC(3,J)=XX1*V(1,3)+XX2*V(2,3)+XX3*V(3,3)                         PM211410
      DO 6900 K=1,3                                                     PM211420
      N1=(NFFT-KAZU)/2                                                  PM211430
      DO 6100 J=1,N1                                                    PM211440
 6100 WORK(J)=0.                                                        PM211450
      DO 6200 J=1,KAZU                                                  PM211460
      N2=N1+J                                                           PM211470
 6200 WORK(N2)=ACC(K,J)                                                 PM211480
      N2=N1+KAZU+1                                                      PM211490
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      DO 6300 J=N2,NFFT                                                 PM211500
 6300 WORK(J)=0.                                                        PM211510
CC                                                                      PM211520
      CALL FFTR (WORK,ACOS1,BSIN1,NFFT,1,S, .02)                        PM211530
CC                                                                      PM211540
      CALL HANNG (ACOS1,BSIN1,  52,ISMTH)                               PM211550
CC                                                                      PM211560
      DO 6500 J=1,52,1                                                  PM211570
 6500 CNTOUR(K, J,I)=     ACOS1(J)                                      PM211580
 6900 CONTINUE                                                          PM211590
      IF(NCASE.GE.51) GO TO 7200                                        PM211600
      J=NCASE+1                                                         PM211610
      DO 7100 I=J,51                                                    PM211620
      DO 7000 IND2=1,52                                                 PM211630
      DO 7000 IND1=1, 3                                                 PM211640
 7000 CNTOUR(IND1,IND2, I)= 1.                                          PM211650
 7100 YY(I)=2. + .5*FLOAT(I)                                            PM211660
 7200 CONTINUE                                                          PM211670
COMMENT     OUTPUTS ARE STORED IN ARRAY (CNTOUR(*,*,*))                 PM211680
      DFRQ=1./( .02*FLOAT(NFFT))                                        PM211690
      DO 7510 J=1,52,1                                                  PM211700
 7510 XX( J)=DFRQ*FLOAT(J-1)                                            PM211710
COMMENT      DESIGN OF OUTPUTS                                          PM211720
COMMENT      DESIGN OF OUTPUTS                                          PM211730
CC                                                                      PM211740
      CALL LEVEL  (CNTOUR, 52, 51, 52,NCASE)                            PM211750
      CALL OUTPUT (CNTOUR, 52, 51,     NCASE,YY)                        PM211760
      IF(IPL3.EQ.0) GO TO 1000                                          PM211770
      CALL CNTPLT (CNTOUR,TT,YY,ZAREA,LABEL1,LABEL2,BUFFER,             PM211780
     1             T3,52,51,750,NSKIP,NCASE)                            PM211790
      GO TO 1000                                                        PM211800
 9900 CONTINUE                                                          PM211810
      CALL CNTPLT (CNTOUR,TT,YY,ZAREA,LABEL1,LABEL2,BUFFER,             PM211820
     1             T3,52,51,750,NSKIP,NCASE)                            PM211830
      WRITE(6,9990)                                                     PM211840
 9990 FORMAT( 1H0,20X,24HJOB NORMALLY TERMINATED.)                      PM211850
      STOP                                                              PM211860
      END                                                               PM211870
```

```
      SUBROUTINE SHB1(G,N,E,V,NEV,NVEC,IND,ITRI,H,P,NL)                 SHB1   0
C                                                                       SHB1  10
C                                                                       SHB1  20
C 196 F2/TC/SHB1                                                        SHB1  30
CC                                                                      SHB1  40
C                                                                       SHB1  50
C PURPOSE                                                               SHB1  60
C     CALCULATION OF EIGENVALUES AND EIGENVECTORS OF A REAL AND         SHB1  70
C     SYMMETRIC MATRIX.                                                 SHB1  80
C                                                                       SHB1  90
C USAGE                                                                 SHB1 100
C     CALL SHB1(G,N,E,V,NEV,NVEC,IND,ITRI,H,P,NL)                       SHB1 110
C                                                                       SHB1 120
C DESCRIPTION OF THE PARAMETERS                                         SHB1 130
C     G   THE INPUT REAL SYMMETRIC MATRIX,ARRAY(NL,NL)                  SHB1 140
C     NL  DIMENSION SIZE OF MAIN PROGAM MATRIX                          SHB1 150
C     N   THE DIMENSION OF DATA MATRIX                                  SHB1 160
C     E   THE EIGENVALUES ARE CONTAINED ON RETURN. ARRAY(NVEC), REAL    SHB1 170
C     V   THE EIGENVECTORS ARE STORED ON RETURN. I-TH COLUMN OF V       SHB1 180
C         CORRESPONS TO I-TH EIGENVALUE. ARRAY(NL,NVEC). REAL           SHB1 190
C     NVEC IF NVEC=0,ONLY EIGENVALUES ARE COMPUTED. OTHERWISE NVEC      SHB1 200
C         EIGENVECTORS ARE COMPUTED.                                    SHB1 210
C     IND IF IND=1, NEV ALGEBRAICALLY LARGEST EIGENVALUES ARE COMPUTED. SHB1 220
C         IF IND=2, NEV ALGEBRAICALLY SMALLEST EIGENVALUES ARE COMPUTED.SHB1 230
C         INTEGER                                                       SHB1 240
C     ITRI IF INPUT MATRIX IS NOT TRI-DIAGONAL ITRI=1                   SHB1 250
C         IF INPUT MATRIX IS TRI-DIAGONAL ITRI=2                        SHB1 260
C     H   H(I,1),I=1,...,N  DIAGONAL ELEMENTS OF TRI-DIAGONALIZED       SHB1 270
C         MATRIX ON RETURN.                                             SHB1 280
C         H(I,2),I=1,...,N-1 CO-DIAGONAL ELEMENTS OF TRI-DIAGONALIZED   SHB1 290
C         MATRIX ON RETURN.                                             SHB1 300
C         ARRAY H(NL,2),REAL                                            SHB1 310
C     P   WORKING STORAGE ARRAY P(N,5), REAL                            SHB1 320
C                                                                       SHB1 330
C REMARKS                                                               SHB1 340
C     THE ORIGINAL MATRIX IS DESTROYED.                                 SHB1 350
C     NVEC MUST NOT EXCEED NEV                                          SHB1 360
C     IF INPUT ORIGINAL MATRIX IS TRI-DIAGONAL,STORE THE DIAGONAL       SHB1 370
C     ELEMENTS IN H(I,1),I=1,...,N, AND THE CO-DIAGONAL ELEMENTS IN     SHB1 380
C     H(2,2),I=1,...,N-1, AND SET ITRI=2 WHEN CALLING THIS SUBROUTINE,  SHB1 390
C     IN THIS CASE ARRAY G IS 1 BY 1 IN CALLING PROGRAM.                SHB1 400
C SUBROUTINE AND FUNCTION SUBPROGRAMS REQUIRED                          SHB1 410
C                                                                       SHB1 420
C     NONE                                                              SHB1 430
C                                                                       SHB1 440
C METHOD                                                                SHB1 450
C     REDUCE A MATRIX TO TRIDIAGONAL FORM BY HOUSEHOLDERS               SHB1 460
C     COMPUTE EIGENVALUES BY BISECTION METHOD.                          SHB1 470
C     COMPUTE EIGENVECTORS BY INVERSE ITERATION.                        SHB1 480
C     RALSTON AND WILF,MATHEMATICAL METHODS FOR DIGITAL COMPUTERS,VOL2, SHB1 490
C      1960 PP 94-155.                                                  SHB1 500
C                                                                       SHB1 510
C                                                                       SHB1 520
      DIMENSION G(NL,NL),E(NL),V(NL,NL),H(NL,2),P(NL,5)                 SHB1 530
      REAL L                                                            SHB1 540
      LOGICAL FIRST                                                     SHB1 550
      IF ((NL-N).LT.0) RETURN                                           SHB1 560
      IF(N.LE.1) RETURN                                                 SHB1 570
C  TRI-DIAGONALIZATION OF GIVEN MATRIX BY HOUSEHOLDER'S METHOD          SHB1 580
      EPSS=1.0E-24                                                      SHB1 590
      NM1=N-1                                                           SHB1 600
      GO TO (100,200),ITRI                                              SHB1 610
  100 IF(N.EQ.2) GO TO 9                                                SHB1 620
      NM2=N-2                                                           SHB1 630
      DO 8 I=1,NM2                                                      SHB1 640
      IP1=I+1                                                           SHB1 650
      SS=0.                                                             SHB1 660
      GK=G(IP1,I)                                                       SHB1 670
      DO 1 J=IP1,N                                                      SHB1 680
    1 SS=SS+G(J,I)*G(J,I)                                               SHB1 690
      IF(SS.LT.EPSS) GO TO 89                                           SHB1 700
      S= SQRT(SS)                                                       SHB1 710
      IF(GK.LT.0.0) S=-S                                                SHB1 720
      H(I,1)=G(I,I)                                                     SHB1 730
      H(I,2)=-S                                                         SHB1 740
      TT=0.                                                             SHB1 750
      TT=1.0E+0/(SS+GK*S)                                               SHB1 760
      T=GK+S                                                            SHB1 770
      G(IP1,I)=T                                                        SHB1 780
      P(IP1,3)=T                                                        SHB1 790
      IP2=I+2                                                           SHB1 800
      DO 2 J=IP2,N                                                      SHB1 810
    2 P(J,3)=G(J,I)                                                     SHB1 820
      DO 4 J=IP1,N                                                      SHB1 830
      T=0.0                                                             SHB1 840
      DO 3 K=IP1,N                                                      SHB1 850
    3 T=T+G(K,J)*P(K,3)                                                 SHB1 860
    4 P(J,1)=T*TT                                                       SHB1 870
      SS=0.                                                             SHB1 880
      DO 5 K=IP1,N                                                      SHB1 890
    5 SS=SS+P(K,3)*P(K,1)                                               SHB1 900
      SS=0.5E+0*SS*TT                                                   SHB1 910
      DO 6 K=IP1,N                                                      SHB1 920
    6 P(K,2)=P(K,1)-SS*P(K,3)                                           SHB1 930
      DO 7 J=IP1,N                                                      SHB1 940
      DO 7 K=J,N                                                        SHB1 950
      G(K,J)=G(K,J)-(P(J,2)*P(K,3)+P(K,2)*P(J,3))                       SHB1 960
    7 G(J,K)=G(K,J)                                                     SHB1 970
      GO TO 8                                                           SHB1 980
   89 TT=0.0E0                                                          SHB1 990
      H(I,1)=G(I,I)                                                     SHB11000
      H(I,2)=0.0E0                                                      SHB11010
    8 G(I,I)=TT                                                         SHB11020
    9 H(NM1,1)=G(NM1,NM1)                                               SHB11030
      H(NM1,2)=G(NM1,N)                                                 SHB11040
      H(N,1)=G(N,N)                                                     SHB11050
      H(N,2)=0.                                                         SHB11060
```

```
  200 CONTINUE                                                          SHB11070
C  CALCULATION OF EIGENVALUES OF TRANSFORMED MATRIX BY BINARY CHOPPING  SHB11080
      TT=ABS(H(1,1))+ABS(H(1,2))                                        SHB11090
      DO 10 I=2,N                                                       SHB11100
      S=ABS(H(I,1))+ABS(H(I,2))+ABS(H(I-1,2))                           SHB11110
C   10 TT=MAX1(TT,S)                                                    SHB11120
   10 TT=AMAX1(TT,S)                                                    SHB11130
      DO 11 I=1,N                                                       SHB11140
   11 P(I,3)=H(I,2)*H(I,2)                                              SHB11150
      ZERO=1.0E-38                                                      SHB11160
      K=1                                                               SHB11170
      IF(IND.EQ.2) TT=-TT                                               SHB11180
      U=TT                                                              SHB11190
      DO 12 I=1,NEV                                                     SHB11200
   12 E(I)=-TT                                                          SHB11210
   13 L=E(K)                                                            SHB11220
      EPS=1.0E-7*ABS(U)                                                 SHB11230
   14 T=0.5E+0*(L+U)                                                    SHB11240
      IF((ABS(U-T).LE.EPS ).OR.(ABS(T-L).LE.EPS)) GO TO 30              SHB11250
      J=0                                                               SHB11260
      I=1                                                               SHB11270
   16 S=H(I,1)-T                                                        SHB11280
   18 IF(S.GE.-ZERO) J=J+1                                              SHB11290
      IF(ABS(S).LE.ZERO) GO TO 20                                       SHB11300
      I=I+1                                                             SHB11310
      IF(I.GT.N) GO TO 21                                               SHB11320
      S=H(I,1)-T-P(I-1,3)/S                                             SHB11330
      GO TO 18                                                          SHB11340
   20 I=I+2                                                             SHB11350
      IF (I.LE.N) GO TO 16                                              SHB11360
   21 GO TO (23,22), IND                                                SHB11370
   22 J=N-J                                                             SHB11380
   23 IF(J.GE.K) GO TO 24                                               SHB11390
      U=T                                                               SHB11400
      GO TO 14                                                          SHB11410
   24 L=T                                                               SHB11420
      M=MINO(J,NEV)                                                     SHB11430
      DO 26 I=K,M                                                       SHB11440
   26 E(I)=T                                                            SHB11450
      GO TO 14                                                          SHB11460
   30 E(K)=T                                                            SHB11470
      K=K+1                                                             SHB11480
      IF(K.LE.NEV) GO TO 13                                             SHB11490
      IF(NVEC.EQ.0) RETURN                                              SHB11500
C CALCULATION OF EIGENVECTORS BY WIELANDT'S INVERSE ITERATION           SHB11510
C     IR=1234567                                                        SHB11520
      DO 600 I=1,NVEC                                                   SHB11530
      DO 44 J=1,N                                                       SHB11540
      P(J,1)=0.                                                         SHB11550
      P(J,2)=H(J,2)                                                     SHB11560
      P(J,3)=H(J,1)-E(I)                                                SHB11570
   44 V(J,I)=1.0E+0                                                     SHB11580
      FIRST=.TRUE.                                                      SHB11590
      DO 50 J=1,NM1                                                     SHB11600
      PJ3=P(J,3)                                                        SHB11610
      HJ1=H(J,2)                                                        SHB11620
      IF(ABS(PJ3).LT.ABS(HJ1)) GO TO 46                                 SHB11630
      SS=HJ1/PJ3                                                        SHB11640
      P(J,4)=0.                                                         SHB11650
      GO TO 48                                                          SHB11660
   46 SS=PJ3/HJ1                                                        SHB11670
      P(J,4)=1.0E+0                                                     SHB11680
      P(J,3)=H(J,2)                                                     SHB11690
      T=P(J+1,3)                                                        SHB11700
      P(J+1,3)=P(J,2)                                                   SHB11710
      P(J,2)=T                                                          SHB11720
      P(J,1)=P(J+1,2)                                                   SHB11730
      P(J+1,2)=0.                                                       SHB11740
   48 P(J,5)=SS                                                         SHB11750
      P(J+1,2)=P(J+1,2)-SS*P(J,1)                                       SHB11760
      P(J+1,3)=P(J+1,3)-SS*P(J,2)                                       SHB11770
C     IF (P(J,3).EQ.0.)  P(J,3)=1.0D-30                                 SHB11780
      IF (P(J,3).EQ.0.)  P(J,3)=1.0E-30                                 SHB11790
   50 CONTINUE                                                          SHB11800
      IF(P(N,3).EQ.0.) P(N,3)=1.0E-30                                   SHB11810
      IF(I.EQ.1.OR.ABS(E(I)-E(I-1)).GE.TT*1.0E-5) GO TO 54              SHB11820
      DO 52 J=1,N                                                       SHB11830
C     IR=IR*4882812S                                                    SHB11840
C  52 V(J,I)=FLOAT(IR)*0.4656613E-9                                     SHB11850
   52 V(J,I)=RANF(0.0)                                                  SHB11860
C  54 CALL OVERFL(II)                                                   SHB11870
   54 CONTINUE                                                          SHB11880
      DO 66 J=1,N                                                       SHB11890
      K=N-J+1                                                           SHB11900
      T=V(K,I)                                                          SHB11910
   62 S=0.                                                              SHB11920
      SS=0.                                                             SHB11930
      IF(K.LT.N) S=V(K+1,I)                                             SHB11940
      IF(K.LT.NM1) SS=V(K+2,I)                                          SHB11950
      V(K,I)=(T-S*P(K,2)-SS*P(K,1))/P(K,3)                              SHB11960
      CALL OVERFL(II)                                                   SHB11970
CC    II=LEGVAR(V(K,I))                                                 SHB11980
      IF(II.NE.1) GO TO 66                                              SHB11990
      DO 64 M=1,N                                                       SHB12000
   64 V(M,I)=V(M,I)*1.0E-5                                              SHB12010
      T=T*1.0E-5                                                        SHB12020
      GO TO 62                                                          SHB12030
   66 CONTINUE                                                          SHB12040
      IF (.NOT.FIRST) GO TO 74                                          SHB12050
      FIRST=.FALSE.                                                     SHB12060
      DO 70 J=1,NM1                                                     SHB12070
      JP1=J+1                                                           SHB12080
      IF(P(J,4).NE.0.0) GO TO 68                                        SHB12090
      V(JP1,I)=V(JP1,I)-P(J,5)*V(J,I)                                   SHB12100
      GO TO 70                                                          SHB12110
   68 T=V(J,I)                                                          SHB12120
      V(J,I)=V(JP1,I)                                                   SHB12130
      V(JP1,I)=T-P(J,5)*V(JP1,I)                                        SHB12140
   70 CONTINUE                                                          SHB12150
      GO TO 54                                                          SHB12160
   74 GO TO (400,500),ITRI                                              SHB12170
  400 IF(N.EQ.2) GO TO 500                                              SHB12180
      DO 78 J=1,NM2                                                     SHB12190
      T=0.                                                              SHB12200
      K=N-J-1                                                           SHB12210
      M=K+1                                                             SHB12220
      DO 76 KK=M,N                                                      SHB12230
   76 T=T+G(KK,K)*V(KK,I)                                               SHB12240
      T=T*G(K,K)                                                        SHB12250
      DO 78 KK=M,N                                                      SHB12260
   78 V(KK,I)=V(KK,I)-T*G(KK,K)                                         SHB12270
  500 T=0.                                                              SHB12280
      DO 80 J=1,N                                                       SHB12290
      SS=ABS(V(J,I))                                                    SHB12300
   80 IF(SS.GT.T) T=SS                                                  SHB12310
      DO 81 J=1,N                                                       SHB12320
   81 V(J,I)=V(J,I)/T                                                   SHB12330
      T=0.                                                              SHB12340
      DO 82 J=1,N                                                       SHB12350
   82 T=T+V(J,I)*V(J,I)                                                 SHB12360
      T=SQRT(T)                                                         SHB12370
      DO 600 J=1,N                                                      SHB12380
  600 V(J,I)=V(J,I)/T                                                   SHB12390
      RETURN                                                            SHB12400
      END                                                               SHB12410
```

```
      SUBROUTINE FFTR (A,ACOS,BSIN,N,IND,S,DT)                          FFTR   0
CC  FOURIER TRANSFORM, FOWARD TRANSFORM AND INVERSE TRANSFORM           FFTR  10
C  A      AR4  (N)        SAMPLES IN TIME-DOMAIN                       FFTR  20
C  ACOS   AR4  (N/2+1)    FOURIER COEFFICIENTS                         FFTR  30
C  BSIN   AR4  (N/2+1)    FOURIER COEFFICIENTS                         FFTR  40
C  N      I4              NUMBER OF F.F.T., SHOULD BE POWER OF 2.      FFTR  50
C  IND    I4              INDEX  .EQ.1   FOWARD TRANSFORM              FFTR  60
C                                .EQ.2   INVERSE TRANSFORM             FFTR  70
C  S      AR4  (N/4-1)    WORKING AREA                                 FFTR  80
C  DT     R4              THE CONSTANT SAMPLING TIME INCREMENT         FFTR  90
```

```
      DIMENSION A(1),ACOS(1),BSIN(1),S(1)                          FFTR 100
      M=N/2                                                        FFTR 110
      MP1=M+1                                                      FFTR 120
      GO TO (1000,2000),IND                                        FFTR 130
CC  FOWARD TRANSFORMATION                                          FFTR 140
 1000     CALL FFT2 (A,ACOS,BSIN,N,S)                             FFTR 150
      DO 1100 I=1,M                                                FFTR 160
      ACOS(I)=ACOS(I)*DT                                           FFTR 170
 1100 BSIN(I)=BSIN(I)*DT                                           FFTR 180
      ACOS(MP1)=BSIN(1)                                            FFTR 190
      BSIN(1)=0.                                                   FFTR 200
      BSIN(MP1)=0.                                                 FFTR 210
      RETURN                                                       FFTR 220
CC  INVERSE TRANSFORM                                              FFTR 230
 2000 NP2=N+2                                                      FFTR 240
      XX=1./(FLOAT(N)*DT)                                          FFTR 250
      A(  1)=   ACOS(  1)*XX                                       FFTR 260
      A(MP1)=   ACOS(MP1)*XX                                       FFTR 270
      DO 2100 I=2,M                                                FFTR 280
      J=NP2-I                                                      FFTR 290
      A(I)=   (ACOS(I)+BSIN(I))*XX                                 FFTR 300
 2100 A(J)=   (ACOS(I)-BSIN(I))*XX                                 FFTR 310
      CALL FFT2 (A,ACOS,BSIN,N,S)                                  FFTR 320
      A(  1)=ACOS(1)                                               FFTR 330
      A(MP1)=BSIN(1)                                               FFTR 340
      DO 2300 I=2,M                                                FFTR 350
      J=NP2-I                                                      FFTR 360
      A(I)=ACOS(I)+BSIN(I)                                         FFTR 370
 2300 A(J)=ACOS(I)-BSIN(I)                                         FFTR 380
      RETURN                                                       FFTR 390
      END                                                          FFTR 400
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```
      SUBROUTINE FFT2(A,A1,B1,N,S)                                 FTR    0
C 189 D6/TC/FTR FAST FOURIER TRANSFORMATION                        FTR   10
      DIMENSION A(1),A1(1),B1(1),S(1)                              FTR   20
      DATA  M/0 /                                                  FTR   30
      IF(N-8)  1000,5,5                                            FTR   40
    5 IF(M-N)  10,30,10                                            FTR   50
   10 M=N                                                          FTR   60
      N4=N/4-1                                                     FTR   70
      FLN=FLOAT(N)                                                 FTR   80
      DO  20  I=1,N4                                               FTR   90
      S(I)=SIN(FLOAT(I)*6.2831853/FLN)                             FTR  100
   20 CONTINUE                                                     FTR  110
   30 N1=N/2                                                       FTR  120
      IF(N.NE.N1*2)  GO TO 1200                                    FTR  130
      N11=N1/2                                                     FTR  140
      DO 100 I=1,N1                                                FTR  150
      I1=I+N1                                                      FTR  160
      A1(I)=A(I)+A(I1)                                             FTR  170
      B1(I)=A(I)-A(I1)                                             FTR  180
  100 CONTINUE                                                     FTR  190
      DO 110 I=1,N1                                                FTR  200
      I01=I+N1                                                     FTR  210
      A(I)=A1(I)                                                   FTR  220
      A(I01)=B1(I)                                                 FTR  230
  110 CONTINUE                                                     FTR  240
      N2=N1                                                        FTR  250
      DO 120 K=1,30                                                FTR  260
      N21=N2/2                                                     FTR  270
      IF(N2.NE.N21*2)  GO TO 1200                                  FTR  280
      DO 130 I=1,N21                                               FTR  290
      I1=I+N21                                                     FTR  300
      I2=I+N11                                                     FTR  310
      I01=I+N1                                                     FTR  320
      I11=I1+N1                                                    FTR  330
      A1(I)=A(I)+A(I1)                                             FTR  340
      B1(I)=A(I)-A(I1)                                             FTR  350
      A1(I2)=A(I01)                                                FTR  360
      B1(I2)=A(I11)                                                FTR  370
      IF(K.EQ.1) GO TO 130                                         FTR  380
      I3=I                                                         FTR  390
      I6=N1+I                                                      FTR  400
      JEND=N11-N21                                                 FTR  410
      DO 140 J=N21,JEND,N21                                        FTR  420
      I3=I3+N2                                                     FTR  430
      I31=I3+N1                                                    FTR  440
      I4=I3+N21                                                    FTR  450
      I41=I4+N1                                                    FTR  460
      I5=J+I                                                       FTR  470
      I6=I6-N21                                                    FTR  480
      J1=N11-J                                                     FTR  490
      APRIME=A(I4)*S(J1)-A(I41)*S(J)                               FTR  500
      BPRIME=A(I41)*S(J1)+A(I4)*S(J)                               FTR  510
      A1(I5)=A(I3)+APRIME                                          FTR  520
      B1(I5)=A(I31)+BPRIME                                         FTR  530
      A1(I6)=A(I3)-APRIME                                          FTR  540
      B1(I6)=-A(I31)+BPRIME                                        FTR  550
  140 CONTINUE                                                     FTR  560
  130 CONTINUE                                                     FTR  570
      IF(N21.EQ.1) RETURN                                          FTR  580
      DO 150 I=1,N1                                                FTR  590
      I01=I+N1                                                     FTR  600
      A(I)=A1(I)                                                   FTR  610
      A(I01)=B1(I)                                                 FTR  620
  150 CONTINUE                                                     FTR  630
      N2=N21                                                       FTR  640
  120 CONTINUE                                                     FTR  650
      RETURN                                                       FTR  660
 1000 WRITE(6,1100)                                                FTR  670
 1100 FORMAT(15H (SUBR. FFT    ) / 24H N MUST BE LARGER THAN 7 )   FTR  680
      RETURN                                                       FTR  690
 1200 WRITE(6,1300)                                                FTR  700
 1300 FORMAT(15H (SUBR. FFT    )/33H N MUST BE A POSITIVE POWER OF 2 ) FTR  710
      RETURN                                                       FTR  720
      END                                                          FTR  730
```

```
          SUBROUTINE HANNG (A1,B1,NN,ICYCLE)                       HANN   0
          DIMENSION A1(1),B1(1)                                    HANN  10
      NNP=NN+ICYCLE                                                HANN  20
      DO 1100 I=1,NNP                                              HANN  30
 1100 A1(I)=SQRT(A1(I)*A1(I)+B1(I)*B1(I))                          HANN  40
      IJK=0                                                        HANN  50
 1300 IJK=IJK+1                                                    HANN  60
      IF(IJK.GT.ICYCLE) GO TO 9000                                 HANN  70
      X  =A1(1)                                                    HANN  80
      XP1=A1(2)                                                    HANN  90
      A1(1)=.5*X+.25* XP1                                          HANN 100
      DO 2100 I=2,NNP                                              HANN 110
      XM1=X                                                        HANN 120
      X  =XP1                                                      HANN 130
      XP1=A1(I+1)                                                  HANN 140
 2100 A1(I)=.5*X+.25*(XP1+XM1)                                     HANN 150
      GO TO 1300                                                   HANN 160
 9000 RETURN                                                       HANN 170
      END                                                          HANN 180
```

```
          SUBROUTINE LEVEL (A,N2,N3,M2,M3)                         LEVL   0
          DIMENSION A(2,N2,N3)                                     LEVL  10
          COMMON /PLT1/ SPECS(35),ZZ( 9)                           LEVL  20
      IDIV=4                                                       LEVL  30
      XD=FLOAT(IDIV)+ .99                                          LEVL  40
      DO 9100 K=1,M3                                               LEVL  50
      DO 9100 I=1, 3                                               LEVL  60
      XX=0.                                                        LEVL  70
      DO 1200 J=1,M2                                               LEVL  80
      IF( XX-A(I,J,K)) 1100,1200,1200                              LEVL  90
 1100 XX=A(I,J,K)                                                  LEVL 100
```

```
1200 CONTINUE                                                          LEVL 110
     XX=XD/XX                                                          LEVL 120
     DO 4100 J=1,M2                                                    LEVL 130
4100 A(I,J,K)= A(I,J,K)     *XX                                       LEVL 140
8100 CONTINUE                                                          LEVL 150
      SPECS(31)=FLOAT(N3)+ .001                                        LEVL 160
      SPECS(32)=FLOAT(N2)+ .001                                        LEVL 170
      SPECS(33)=FLOAT(IDIV)+ .001                                      LEVL 180
     DO 9100 I=1,IDIV                                                  LEVL 190
9100 ZZ(I)=FLOAT(I)                                                    LEVL 200
     RETURN                                                            LEVL 210
     END                                                               LEVL 220
```

```
        SUBROUTINE OUTPUT (A,N2,N3,    M3,Y)                           OTPT   0
        DIMENSION A(3,N2,N3),Y(1)                                      OTPT  10
        DIMENSION IX(51)                                               OTPT  20
     DO 6000 I=1,3                                                     OTPT  30
     WRITE(6,1100)                                                     OTPT  40
1100 FORMAT(1H1)                                                       OTPT  50
     GO TO (1110,1120,1130),I                                          OTPT  60
1110 J=10HMAJOR                                                        OTPT  70
     K=10H                                                             OTPT  80
     GO TO 1200                                                        OTPT  90
1120 J=10HINTERMEDIA                                                   OTPT 100
     K=10HTE                                                           OTPT 110
     GO TO 1200                                                        OTPT 120
1130 J=10HMINOR                                                        OTPT 130
     K=10H                                                             OTPT 140
1200 WRITE(6,1300) J,K                                                 OTPT 150
1300 FORMAT(1H ,5H** (  ,2A10,19HPRINCIPAL AXIS ) **)                  OTPT 160
     WRITE(6,1100)                                                     OTPT 170
     WRITE(6,2001)                                                     OTPT 180
2001 FORMAT( 1H ,9X,123H0.0* * * *2.5* * * *5.0* * * *7.5* * * 10.0* * OTPT 190
    1* 12.5* * * 15.0* * * 17.5* * * 20.0* * * 22.5* * * 25.0* * * 27.5OTPT 200
    2* * * 30.0)                                                       OTPT 210
     DO 3200 L=1,52                                                    OTPT 220
     J=53-L                                                            OTPT 230
     DO 3100 K=1,M3                                                    OTPT 240
     II=A(I,J,K)+1.                                                    OTPT 250
     GO TO (3001,3002,3003,3004,3005                          ),II     OTPT 260
3001 IX(K)=2H                                                          OTPT 270
     GO TO 3100                                                        OTPT 280
3002 IX(K)=2H 1                                                        OTPT 290
     GO TO 3100                                                        OTPT 300
3003 IX(K)=2H 2                                                        OTPT 310
     GO TO 3100                                                        OTPT 320
3004 IX(K)=2H 3                                                        OTPT 330
     GO TO 3100                                                        OTPT 340
3005 IX(K)=2H 4                                                        OTPT 350
3100 CONTINUE                                                          OTPT 360
     WRITE(6,5120)   Y(J),(IX(K),K=1,M3)                               OTPT 370
     WRITE(6,3140)                                                     OTPT 380
3140 FORMAT(1H+,130X,1H*)                                              OTPT 390
3200 CONTINUE                                                          OTPT 400
5120 FORMAT(    1H ,     F7.3,3X,1H*,8X,51A2)                          OTPT 410
6000 WRITE(6,2001)                                                     OTPT 420
     RETURN                                                            OTPT 430
     END                                                               OTPT 440
```

```
        SUBROUTINE CNTPLT (A,X,Y,Z,LINE1,LINE2,BUFXYZ,                 CNTP   0
   1                       XEND,N2,N3,LENGTH,INDEX,MM)                 CNTP  10
        COMMON /PLT1/ SPECS(35),ZLEVEL( 9)                             CNTP  20
        DIMENSION A(3,N2,N3),Z(N3,N2),BUFXYZ(LENGTH)                   CNTP  30
        DIMENSION X(1),Y(1),LINE1(1),LINE2(1)                          CNTP  40
     IF(INDEX.EQ.999) GO TO 9000                                       CNTP  50
     LINE1(5)=0                                                        CNTP  60
     LINE2(7)=0                                                        CNTP  70
     I=IFIX(XEND/5.+.99 )                                              CNTP  80
     XX3=FLOAT(I)*5.                                                   CNTP  90
      SPECS( 1)=1.                                                     CNTP 100
      SPECS( 2)=2.                                                     CNTP 110
      SPECS( 3)=XX3                                                    CNTP 120
      SPECS( 4)=0.                                                     CNTP 130
      SPECS( 5)=9.                                                     CNTP 140
      SPECS( 6)=0.                                                     CNTP 150
     XL=.1F                                                            CNTP 160
     IF(XX3.LE.15.) XL=.32                                             CNTP 170
      SPECS( 7)=XX3*XL                                                 CNTP 180
      SPECS( 8)=2.                                                     CNTP 190
      SPECS( 9)=XX3+.001                                               CNTP 200
     IF(XX3.LE.15.) SPECS( 9)=2.*SPECS( 9)                             CNTP 210
      SPECS(10)=4.001                                                  CNTP 220
      SPECS(11)=1.                                                     CNTP 230
      SPECS(12)=99.                                                    CNTP 240
      SPECS(17)= .1                                                    CNTP 250
      SPECS(18)= .1                                                    CNTP 260
      SPECS(19)= .0                                                    CNTP 270
      SPECS(20)= .0                                                    CNTP 280
      SPECS(21)=1.                                                     CNTP 290
      SPECS(24)= .07                                                   CNTP 300
      SPECS(28)=1.                                                     CNTP 310
         CALL SAXLIB (SPECS)                                           CNTP 320
      SPECS( 9)=XX3/5.+.001                                            CNTP 330
     IF(XX3.LE.15.) SPECS( 9)=2.*SPECS( 9)                             CNTP 340
         CALL NODLIB (SPECS)                                           CNTP 350
      SPECS(17)= .15                                                   CNTP 360
      SPECS(18)= .15                                                   CNTP 370
         CALL TITLEB (11HTIME (SEC.),SPECS)                            CNTP 380
     IM=SPECS(31)                                                      CNTP 390
     JM=SPECS(32)                                                      CNTP 400
     DO 4100 K=1,3                                                     CNTP 410
      SPECS( 2)=2.+   FLOAT(K-1)*2.375                                 CNTP 420
         CALL AXLILI (SPECS)                                           CNTP 430
      SPECS(27)=-0.15                                                  CNTP 440
         CALL SAXLIR (SPECS)                                           CNTP 450
      SPECS(17)= .1                                                    CNTP 460
      SPECS(18)= .1                                                    CNTP 470
      SPECS(26)= .07                                                   CNTP 480
         CALL NODLIL (SPECS)                                           CNTP 490
      SPECS(17)= .15                                                   CNTP 500
      SPECS(18)= .15                                                   CNTP 510
         CALL TITLEL (10HFREQ. (HZ),SPECS)                             CNTP 520
      KP=4-K                                                           CNTP 530
     DO 2100 J=1,JM                                                    CNTP 540
     DO 2100 I=1,IM                                                    CNTP 550
2100 Z(I,J)=A(KP,J,I)                                                  CNTP 560
      SPECS( 3)=X(MM)                                                  CNTP 570
      SPECS( 7)=X(MM)*XL                                               CNTP 580
         CALL CONLI (X,Y,Z,ZLEVEL,BUFXYZ,LENGTH,SPECS)                 CNTP 590
      SPECS( 3)=XX3                                                    CNTP 600
      SPECS( 7)=XX3*XL                                                 CNTP 610
      SPECS(25)= .0                                                    CNTP 620
     GO TO (3100,3200,3300),KP                                         CNTP 630
3100      CALL TITLET ( SHMAJOR         ,SPECS)                       CNTP 640
     GO TO 4100                                                        CNTP 650
3200      CALL TITLET (12HINTERMEDIATE,SPECS)                          CNTP 660
     GO TO 4100                                                        CNTP 670
3300      CALL TITLET ( SHMINOR         ,SPECS)                       CNTP 680
4100 CONTINUE                                                          CNTP 690
      SPECS( 9)=XX3+.001                                               CNTP 700
      IF(XX3.LE.15.) SPECS( 9)=2.*SPECS( 9)                            CNTP 710
         CALL SAXLIT (SPECS)                                           CNTP 720
      SPECS( 9)=XX3/5.+.001                                            CNTP 730
      IF(XX3.LE.15.) SPECS( 9)=2.*SPECS( 9)                            CNTP 740
      SPECS(17)= .1                                                    CNTP 750
      SPECS(18)= .1                                                    CNTP 760
         CALL NODLIT (SPECS)                                           CNTP 770
      SPECS(22)=1.                                                     CNTP 780
      SPECS(23)= 9.5                                                   CNTP 790
      RULE=1.                                                          CNTP 800
         CALL TITLEG (RULE,LINE2,SPECS)                                CNTP 810
      SPECS(17)= .15                                                   CNTP 820
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      SPECS(18)= .15                                                    CNTP 830
      SPECS(23)= 9.75                                                   CNTP 840
         CALL TITLEG (RULE,LINE1,SPECS)                                 CNTP 850
         CALL NXTFRM (SPECS)                                            CNTP 860
      RETURN                                                            CNTP 870
 9000 WRITE(6,9100)                                                     CNTP 880
 9100 FORMAT(1H0,20X,19HPLOTTER TERMINATED.)                            CNTP 890
      SPECS(12)=99.                                                     CNTP 900
         CALL GDSEND (SPECS)                                            CNTP 910
      RETURN                                                            CNTP 920
      END                                                               CNTP 930
```

```
      PROGRAM PGM51  (INPUT,OUTPUT,PUNCH,                                PM51   0
     1                TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=PUNCH)             PM51  10
CC                                                                      PM51  20
COMMENT    GENERATING NON-STATIONARY SIMULATED MOTIONS                  PM51  30
CC                                                                      PM51  40
C          SUBROUTINES, REQUIRED                                        PM51  50
C          SUBROUTINE SIMLTE                                            PM51  60
C          SUBROUTINE BASLIN                                            PM51  70
C          SUBROUTINE LINCOR                                            PM51  80
C          FUNCTION  SHAPE                                              PM51  90
C          FUNCTION  FREQ                                               PM51 100
COMMENT                                                                 PM51 110
      DIMENSION DATA(  1501),ACC(500),DATA1( 3, 1501), TT4(3)           PM51 120
      DIMENSION NAME(8) , FX(10)   , LABEL1(3)                          PM51 130
      DATA LABEL1 /3H  I,3H II,3HIII/                                   PM51 140
  100 FORMAT(F15.14)                                                    PM51 150
  101 FORMAT(2I8,8F8.0)                                                 PM51 160
  102 FORMAT(8A10)                                                      PM51 170
  103 FORMAT(3I9,26X,A 7)                                               PM51 180
CC                                                                      PM51 190
CC  DUMMY   =  INITIAL VALUE FOR GENERATING A UNIFORM RANDOM NUMBER     PM51 200
CC                                                                      PM51 210
      READ(5,100) DUMMY                                                 PM51 220
      DUMMY=DUMMY*1.E6                                                  PM51 230
      R1   =RANF(DUMMY)                                                 PM51 240
      WRITE(6,230) DUMMY,R1                                             PM51 250
      DO 1000 I=1,10                                                    PM51 260
      DUMMY=RANF(0.0)                                                   PM51 270
 1000 WRITE(6,240) DUMMY                                                PM51 280
CC                                                                      PM51 290
CC  NCOMP   =  NUMBER OF COMPONENTS, GENERATED SIMULTENEOUSLY           PM51 300
CC  MCASE   =  NUMBER OF SINUSOIDAL WAVES, BEING SUPERPOSED             PM51 310
CC  T1      =  TIME LENGTH OF WINDOW                                    PM51 320
CC  T2      =  TIME, SKIPPED                                            PM51 330
CC  T3      =  TERMINATE LENGTH OF TIME                                 PM51 340
CC  TT4     =  LINEAR CORRECTION ON A GENERATED ACCELEROGRAM IS          PM51 350
C              DONE FROM ( 0.0) SECS. TO (TT4) SECS.                    PM51 360
C              IF(TT4.LT.0.0) THEN LINEAR CORRECTION WILL NOT           PM51 370
C              BE EMPLOYED                                              PM51 380
CC  NAME    =  LABEL ON PRINT OUT SHEETS                                PM51 390
CC  NSAMP   =  IDENTIFICATION NUMBER ON PUNCHED OUT CARDS               PM51 400
CC  IPRINT  =  IF(IPRINT.EQ.0) THEN, INTEGRATED VELOCITIES AND DOUBLE   PM51 410
C              INTEGRATED DISPLACEMENTS OF THE ACCELEROGRAM WILL NOT BE PM51 420
C              PRINTED OUT                                              PM51 430
CC  IPUNCH  =  IF(IPUNCH.EQ.0) THEN, THE PUNCHED CARDS OF THE SIMULATED PM51 440
C              MOTIONS WILL NOT BE PRODUCED                             PM51 450
CC  LABEL   =  LABEL ON GENERATED ACCELEROGRAM CARDS DECK               PM51 460
CC                                                                      PM51 470
 2000 READ(5,101) NCOMP,MCASE,T1,T2,T3,DT,(TT4(I),I=1,NCOMP)           PM51 480
      IF((NCOMP.LE. 0).OR.(NCOMP.GE. 4)) GO TO 9900                     PM51 490
      READ(5,102) NAME                                                  PM51 500
      READ(5,103) NSAMP,IPRINT,IPUNCH,LABEL                             PM51 510
CC                                                                      PM51 520
COMMENT                                                                 PM51 530
CC                                                                      PM51 540
      WRITE(6,200) NAME                                                 PM51 550
      GMAX1= .0                                                         PM51 560
      DO 5000 II=1,NCOMP                                                PM51 570
      T4=TT4(II)                                                        PM51 580
      WRITE(6,205) II                                                   PM51 590
      WRITE(6,210) T1,T2,T3,DT,T4                                       PM51 600
      WRITE(6,220)       MCASE                                          PM51 610
  200 FORMAT(1H1,42(2H* ),/1H ,2H* ,8A10,2H* ,/1H ,42(2H* ))            PM51 620
  205 FORMAT(/1H0,34HCOMPONENT IDENTIFICATION NUMBER = ,I4)             PM51 630
  210 FORMAT(/1H0,25HTIME LENGTH OF WINDOW   = ,F15.7,7H (SEC.),        PM51 640
     1       /1H ,25HTIME INTERVAL, SKIPPED = ,F15.7,7H (SEC.),        PM51 650
     2       /1H ,25HTERMINATE LENGTH       = ,F15.7,7H (SEC.),        PM51 660
     3       /1H0,25HTIME INTERVAL          = ,F15.7,7H (SEC.),        PM51 670
     4       /1H0,47HLINEAR BASELINE ADJUSTMENT FROM ( 0.0) SECS TO ,   PM51 680
     5                                       F15.7,7H (SEC.))          PM51 690
  220 FORMAT(/1H0,25HMCASE, SET OF COSINE    = ,I7,8X,7H (SETS))       PM51 700
  230 FORMAT(/1H0,25HRANDOM NUMBER (R1)      = ,F15.7,                 PM51 710
     1       /1H ,25H         (RANF(R1))     = ,F15.7)                 PM51 720
  240 FORMAT(1H ,25X,F15.7)                                             PM51 730
      NDATA=T3/DT+ .001                                                 PM51 740
      DO 2100 I=1,NDATA                                                 PM51 750
 2100 DATA(  I)= .0                                                     PM51 760
CC                                                                      PM51 770
COMMENT  SIMULATION OF RANDOM PROCESS                                   PM51 780
CC                                                                      PM51 790
         CALL SIMLTE (DATA,ACC,DT,T1,   T3,MCASE , II )                 PM51 800
CC                                                                      PM51 810
COMMENT  MULTIPLY AN APPROPRIATE DETERMINISTIC SHAPE FUNCTION           PM51 820
CC                                                                      PM51 830
      DO 3100 I=1,NDATA                                                 PM51 840
 3100 DATA(  I)=DATA(  I)*SHAPE(DT*FLOAT(I-1)   ,  II)                  PM51 850
CC                                                                      PM51 860
COMMENT  ZERO BASELINE CORRECTION                                       PM51 870
CC                                                                      PM51 880
         CALL BASLIN (DATA,DT,NDATA,GMAX,TMAX,IPRINT)                   PM51 890
         CALL LINCOR (DATA,DT,T3,T4,   NDATA)                           PM51 900
CC                                                                      PM51 910
      GMAX1=AMAX1(GMAX ,GMAX1)                                          PM51 920
      DO 4000 I=1,NDATA                                                 PM51 930
 4000 DATA1(II,I)=DATA (   I)                                           PM51 940
 5000 CONTINUE                                                          PM51 950
CC                                                                      PM51 960
COMMENT PRINT AND PUNCH OUT OF GENERATED ACCELEROGRAMS                  PM51 970
CC                                                                      PM51 980
      GMAX= .9999    /GMAX1                                             PM51 990
      DO 9500 II=1,NCOMP                                                PM511000
      LABEL2    =LABEL1(II)                                             PM511010
      DO 8100 I=1,NDATA                                                 PM511020
 8100 DATA(  I)=GMAX*DATA1(II,I)                                        PM511030
      WRITE(6,8200) NSAMP , II                                          PM511040
 8200 FORMAT(//1H0,27HGENERATED EARTHQUAKE MOTION,                      PM511050
     1        /1H0,34HSAMPLE NUMBER                    =  ,I8,         PM511060
     2        /1H ,34HCOMPONENT IDENTIFICATION NUMBER = ,I8,/)         PM511070
      I=0                                                               PM511080
      LINE=0                                                            PM511090
 8300 I=I+1                                                             PM511100
      IF(I.GT.NDATA) GO TO 8800                                         PM511110
      J=I-I/10*10                                                       PM511120
      IF(J.EQ.0) J=10                                                   PM511130
      FX(J)=DATA(  I)                                                   PM511140
      IF(J.NE.10) GO TO 8300                                            PM511150
      IF(MOD(LINE,5).EQ.0) WRITE(6,8500)                                PM511160
 8500 FORMAT(1H )                                                       PM511170
      LINE=LINE+1                                                       PM511180
      WRITE(6,8600) FX,NSAMP,LABEL,LINE , LABEL2                        PM511190
 8600 FORMAT(1H ,10F10.6,I8,2X,A 7,1X,I8,1X,A3)                         PM511200
      IF(IPUNCH.NE.0) WRITE(7,8700) FX,NSAMP,LABEL,LINE , LABEL2        PM511210
 8700 FORMAT(10F6.4,5HSAMP=,I2, A7, I3, A3)                             PM511220
      GO TO 8300                                                        PM511230
 8800 CONTINUE                                                          PM511240
 9500 CONTINUE                                                          PM511250
      GO TO 2000                                                        PM511260
 9900 CONTINUE                                                          PM511270
      WRITE(6,9990)                                                     PM511280
 9990 FORMAT( 1H0,20X,24HJOB NORMALLY TERMINATED.)                      PM511290
      STOP                                                              PM511300
      END                                                               PM511310
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      SUBROUTINE SIMLTE (DATA,ACC,DT,T1,   T3,MCASE  ,  II)             SIML   0
      DIMENSION DATA(1),ACC(1)                                          SIML  10
COMMENT   FUNCTION (FREQ), DEFINING TIME-DEPENDENT POWER SPECTRAL       SIML  20
C                        DENSITY FUNCTION IS REQUIRED.                  SIML  30
COMMENT   REF     K.TOKI, H.GOTO, T.AKIYOSHI                            SIML  40
C           GENERATION OF ARTIFICIAL EARTHQUAKES ON DIGITAL             SIML  50
C           COMPUTER     3RD J.E.E.S.  OCT., 1966                       SIML  60
C         K.TOKI     SIMULATION OF EARTHQUAKE MOTION AND ITS           SIML  70
C           APPLICATION   BULL. DISAST. PREV. RES.  MAR., 1968SIML  80
C         H.GOTO, K.TOKI   STRUCTURAL RESPONSE TO NONSTATIONARY         SIML  90
C                        RANDOM EXCITATION     4TH W.C.E.E.  JAN. 69 SIML 100
COMMENT   GENERATION OF STATIONARY WAVE                                 SIML 110
      UB=1./(2.*DT)                                                     SIML 120
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C      NSAMPL=200                                                        SIML 130
C      RMS=1.41421356/SQRT(FLOAT(NSAMPL))                                SIML 140
       NSAMPL=MCASE                                                      SIML 150
       T4=.5*T1                                                          SIML 160
       T5=T3-T4                                                          SIML 170
       NN=T1/DT+ .001                                                    SIML 180
       J=0                                                               SIML 190
COMMENT    GENERATION OF UNIFORM RANDOM NUMBER                           SIML 200
 1200 CONTINUE                                                           SIML 210
       XX=RANF(0.0)                                                      SIML 220
       YY=RANF(0.0)                                                      SIML 230
       ZZ=RANF(0.0)                                                      SIML 240
       XX=XX*UB                                                          SIML 250
       YY=T3*YY                                                          SIML 260
CC  XX        FREQUENCY VARIABLE, UNIFORMLY DISTRIBUTED                  SIML 270
C             FROM ( 0.0) TO (NYQUIST FREQUENCY)                         SIML 280
CC  YY        TIME VARIABLE, UNIFORMLY DISTRIBUTED FROM ( 0.0) TO (T3)   SIML 290
CC                                                                       SIML 300
       PP=FREQ(YY,XX   ,   II)                                           SIML 310
       IF(ZZ.GE.PP) GO TO 1200                                           SIML 320
       J=J+1                                                             SIML 330
       XX=6.28318853*XX*DT                                               SIML 340
COMMENT    GENERATING RANDOM PHASE ANGLE                                 SIML 350
       ZZ=RANF(0.0)                                                      SIML 360
       ZZ=6.28318853*ZZ                                                  SIML 370
       COSI=COS(XX)                                                      SIML 380
       SIN1=SIN(XX)                                                      SIML 390
       DO 1700 I=1,NN                                                    SIML 400
       IM1=I-1                                                           SIML 410
       IF(MOD(IM1,50).EQ.0) GO TO 1600                                   SIML 420
       XX  =COSI*COS1-SINE*SIN1                                          SIML 430
       SINE=SINE*COS1+COSI*SIN1                                          SIML 440
       COSI=XX                                                           SIML 450
       GO TO 1700                                                        SIML 460
 1600 COSI=COS(FLOAT(IM1)*XX+ZZ)                                        SIML 470
       SINE=SIN(FLOAT(IM1)*XX+ZZ)                                        SIML 480
 1700 ACC(I)=        COSI                                                SIML 490
COMMENT    FILTERING THROUGH COSINE-BELL FUNCTION                        SIML 500
C          TO OBTAIN CONTINUITY AT THE ENDS                              SIML 510
       XX=6.28318853/FLOAT(NN)                                           SIML 520
       ACC(  1)=0.0                                                      SIML 530
       K=NN/2                                                            SIML 540
       DO 2100 I=2,K                                                     SIML 550
       IM1=NN-I+2                                                        SIML 560
       ZZ=.5*(1.-COS(XX*FLOAT(I-1)))                                     SIML 570
       ACC(I  )=ACC(I  )*ZZ                                              SIML 580
 2100 ACC(IM1)=ACC(IM1)*ZZ                                               SIML 590
       N1=(YY-T4)/DT                                                     SIML 600
       N2=1                                                              SIML 610
       IF(YY.LE.T4) N2=(T4-YY)/DT+1.                                     SIML 620
       N3=NN                                                             SIML 630
       IF(YY.GT.T5) N3=NN-IFIX((YY-T5)/DT       )                        SIML 640
       DO 2300 I=N2,N3                                                   SIML 650
       IM1=N1+I                                                          SIML 660
 2300 DATA(  IM1)=DATA(  IM1)+ACC(I)                                     SIML 670
       IF(J.LT.NSAMPL) GO TO 1200                                        SIML 680
       XX=RANF(-1.)                                                      SIML 690
       WRITE(6,3100) XX                                                  SIML 700
 3100 FORMAT(1H0,10X,41H***** LAST PRECEEDING RANDOM NUMBER *****,       SIML 710
     1      /1H ,20X,F15.7)                                              SIML 720
       RETURN                                                            SIML 730
       END                                                               SIML 740
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          SUBROUTINE BASLIN (ZZ,DT,N,GMAX,TMAX,IP)                       BSLN   0
C  BASELINE ADJUSTMENT OF ACCELEROGRAMS                                  BSLN  10
C  REF.  G.V.BERG AND G.W.HOUSNER  BSSA  VOL. 51, NO. 2  PP 175- PP 189 BSLN  20
          DIMENSION ZZ(1),VO(10)                                         BSLN  30
       NP1=N+1                                                           BSLN  40
       ZZ(NP1)=0.                                                        BSLN  50
       DT2=.5*DT                                                         BSLN  60
       DT6=DT*DT/6.                                                      BSLN  70
       WRITE(6,1)                                                        BSLN  80
       Z1=0.                                                             BSLN  90
       V =0.                                                             BSLN 100
       VMAX=0.                                                           BSLN 110
       Y1=0.                                                             BSLN 120
       Y2=0.                                                             BSLN 130
       Y3=0.                                                             BSLN 140
       DO 200 I=1,NP1                                                    BSLN 150
       Z2=ZZ(I)                                                          BSLN 160
       V=V+DT2*(Z1+Z2)                                                   BSLN 170
       X1=FLOAT(I)                                                       BSLN 180
       X2=X1*X1                                                          BSLN 190
       X3=X2*X1                                                          BSLN 200
       V1=V/DT                                                           BSLN 210
       Y1=Y1+(X1-.51*V1+(-.166666667*X1+.125)*Z1+(-.33333333*X1+.20833333BSLN 220
     1)*Z2                                                               BSLN 230
       Y2=Y2+(X2-X1+.333333333)*V1+(-.16666667*X2+.25*X1-.1)*Z1+(-.3333333BSLN 240
     13*X2+.416666667*X1-.15)*Z2                                         BSLN 250
       Y3=Y3+(X3-1.5*X2+X1-.25)*V1+(-.16666667*X3+.375*(X2+X1)+.08333333)BSLN 260
     1*Z1+(-.33333333*X3+.625*X2-1.125*X1+.11666667)*Z2                  BSLN 270
       Z1=Z2                                                             BSLN 280
       Z2=ABS(V)                                                         BSLN 290
       IF(Z2.LE.VMAX) GO TO 100                                          BSLN 300
       VMAX=Z2                                                           BSLN 310
       TVMAX=(X1-1.)*DT                                                  BSLN 320
100 K=I-I/10*10                                                          BSLN 330
       IF(K.EQ.0) K=10                                                   BSLN 340
       VO(K)=V                                                           BSLN 350
       IF(K.NE.10) GO TO 200                                             BSLN 360
       IF(IP.EQ.0) GO TO 190                                             BSLN 370
       IF(MOD(I,50).EQ.0) WRITE(6,7)                                     BSLN 380
       WRITE(6,2) VO                                                     BSLN 390
190 CONTINUE                                                             BSLN 400
200 CONTINUE                                                             BSLN 410
       WRITE(6,4) VMAX,TVMAX                                             BSLN 420
       WRITE(6,6)                                                        BSLN 430
       Z2=1./FLOAT(NP1)                                                  BSLN 440
       X1=Z2*Z2*Z2                                                       BSLN 450
       X2=Z2*X1                                                          BSLN 460
       Y1=Y1*X1                                                          BSLN 470
       Y2=Y2*X2                                                          BSLN 480
       Y3=Y3*X2*Z2                                                       BSLN 490
       C0=- 300.*Y1 +  900.*Y2 -  630.*Y3                                BSLN 500
       C1= 1890.*Y1 - 5760.*Y2 + 4200.*Y3                                BSLN 510
       C2=-1890.*Y1 + 6300.*Y2 - 4725.*Y3                                BSLN 520
       C1=C1*Z2                                                          BSLN 530
       C2=C2*Z2*Z2                                                       BSLN 540
       V =0.                                                             BSLN 550
       D =0.                                                             BSLN 560
       Z1=0.                                                             BSLN 570
       GMAX=0.                                                           BSLN 580
       VMAX=0.                                                           BSLN 590
       DMAX=0.                                                           BSLN 600
       DO 600 I=1,N                                                      BSLN 610
       X1=FLOAT(I)                                                       BSLN 620
       X2=C0+C1*X1+C2*X1*X1                                              BSLN 630
       ZZ(I)=ZZ(I)+X2                                                    BSLN 640
       X3=ABS(ZZ(I))                                                     BSLN 650
       IF(X3.LE.GMAX) GO TO 300                                          BSLN 660
       GMAX=X3                                                           BSLN 670
        TMAX=(X1-1.)*DT                                                  BSLN 680
300 D =D +V *DT+DT6*(2.*Z1+ZZ(I))                                        BSLN 690
       X3=ABS(D )                                                        BSLN 700
       IF(X3.LE.DMAX) GO TO 400                                          BSLN 710
       DMAX=X3                                                           BSLN 720
       TDMAX=(X1-1.)*DT                                                  BSLN 730
400 V=V+DT2*(Z1+ZZ(I))                                                   BSLN 740
       Z1=ZZ(I)                                                          BSLN 750
       X3=ABS(V)                                                         BSLN 760
       IF(X3.LE.VMAX) GO TO 500                                          BSLN 770
       VMAX=X3                                                           BSLN 780
       TVMAX=(X1-1.)*DT                                                  BSLN 790
500 K=I-I/10*10                                                          BSLN 800
       IF(K.EQ.0) K=10                                                   BSLN 810
       VO(K)=V                                                           BSLN 820
```

```
      IF(K.NE.10) GO TO 600                                             BSLN 830
      IF(IP.EQ.0) GO TO 590                                             BSLN 840
      IF(MOD(I,50).EQ.0) WRITE(6,7)                                     BSLN 850
      WRITE(6,2) VO                                                     BSLN 860
  590 CONTINUE                                                          BSLN 870
  600 CONTINUE                                                          BSLN 880
      WRITE(6,3) GMAX, TMAX                                             BSLN 890
      WRITE(6,4) VMAX,TVMAX                                             BSLN 900
      WRITE(6,5) DMAX,TDMAX                                             BSLN 910
      RETURN                                                            BSLN 920
    1 FORMAT(1H0,43HINTEGRATED VELOCITY OF ORIGINAL SAMPLE WAVE)        BSLN 930
    2 FORMAT(1H ,10F12.4)                                               BSLN 940
    3 FORMAT(1H0,20X,7HGMAX = ,F15.7,8H  ( T = ,F9.3,6H SEC.))          BSLN 950
    4 FORMAT(1H ,20X,7HVMAX = ,F15.7,8H  ( T = ,F9.3,6H SEC.))          BSLN 960
    5 FORMAT(1H ,20X,7HDMAX = ,F15.7,8H  ( T = ,F9.3,6H SEC.))          BSLN 970
    6 FORMAT(1H0,44HINTEGRATED VELOCITY OF CORRECTED SAMPLE WAVE)       BSLN 980
    7 FORMAT(1H )                                                       BSLN 990
      END                                                               BSLN1000
```

```
      SUBROUTINE LINCOR (ACC,DT,T3,T4,   N)                             LNCR   0
      DIMENSION ACC(1)                                                  LNCR  10
      IF(T4.LE..0) GO TO 9000                                           LNCR  20
      NN=T4/DT+1.001                                                    LNCR  30
      XX=ACC(1)/T4                                                      LNCR  40
      DO 1100 I=1,NN                                                    LNCR  50
 1100 ACC(I)=ACC(I)-XX*(T4-DT*FLOAT(I-1))                               LNCR  60
 9000 RETURN                                                            LNCR  70
      END                                                               LNCR  80
```

```
      FUNCTION FREQ (TT,XX,II)                                          FREQ   0
CC                                                                      FREQ  10
COMMENT  AN ARBITRARY FUNCTION, WHICH DEFINES FREQUENCY CONTENTS        FREQ  20
CC                                                                      FREQ  30
CC         IT IS RECOMMENDED TO GIVE THE TIME INDEPENDENT VALUE TO THE  FREQ  40
C          POWER AT TIME (T).                                           FREQ  50
CC         NOTE THAT IF THE POWER OF THE PROCESS (VARIANCE) AT TIME     FREQ  60
C          (T) IS DEPENDENT UPON TIME, THE INTENSITY OF THE PROCESS     FREQ  70
C          WILL NOT BE GIVEN APPROPRIATELY BY MULTIPLYING               FREQ  80
C          THE DETERMINISTIC SHAPE FUNCTION                             FREQ  90
CC                                                                      FREQ 100
      GO TO (1000,2000,3000), II                                        FREQ 110
 1000 ZZ= .2                                                            FREQ 120
      GO TO 4000                                                        FREQ 130
 2000 ZZ= .3                                                            FREQ 140
      GO TO 4000                                                        FREQ 150
 3000 ZZ= .6                                                            FREQ 160
 4000 CONTINUE                                                          FREQ 170
      FG=-.08*TT+3.4                                                    FREQ 180
      FF=XX/FG                                                          FREQ 190
      FF=FF*FF                                                          FREQ 200
      HG=4.*ZZ*ZZ                                                       FREQ 210
      XX  =(1.+HG*FF)/((1.-FF)*(1.-FF)+HG*FF)                           FREQ 220
      XX  =XX * HG / (1.+HG)                                            FREQ 230
      XX  =XX / FG                                                      FREQ 240
COMMENT    1. = -.08 * 30. + 3.4                                        FREQ 250
CC    XX  =XX * 1.                                                      FREQ 260
      FREQ=XX                                                           FREQ 270
      RETURN                                                            FREQ 280
      END                                                               FREQ 290
```

```
      FUNCTION SHAPE (TT,II)                                            SHPE   0
CC                                                                      SHPE  10
COMMENT  AN ARBITRARY FUNCTION, WHICH GIVES THE DETERMINISTIC INTENSITY SHPE  20
CC                                                                      SHPE  30
CC         THE FUNCTION (SHAPE) WILL GIVE DETERMINISTIC INTENSITY       SHPE  40
C          FOR THE PROCESS OF UNIFORM VARIANCE                          SHPE  50
CC                                                                      SHPE  60
      IF(TT.GE.  .5) GO TO 2100                                         SHPE  70
      GO TO (5000,5400,5400), II                                        SHPE  80
 2100 IF(TT.GE. 1.0) GO TO 2200                                         SHPE  90
      GO TO (5100,5400,5400), II                                        SHPE 100
 2200 IF(TT.GE. 3.6) GO TO 2300                                         SHPE 110
      GO TO (5100,5900,5500), II                                        SHPE 120
 2300 IF(TT.GE. 4.125) GO TO 2400                                       SHPE 130
      GO TO (5900,5100,5500), II                                        SHPE 140
 2400 IF(TT.GE. 6.0) GO TO 2500                                         SHPE 150
      GO TO (5900,5500,5100), II                                        SHPE 160
 2500 IF(TT.GE.12.0) GO TO 2600                                         SHPE 170
      GO TO (6000,5600,5100), II                                        SHPE 180
 2600 IF(TT.GE.18.0) GO TO 2700                                         SHPE 190
      GO TO (6100,5700,5200), II                                        SHPE 200
 2700 IF(TT.GE.24.0) GO TO 2800                                         SHPE 210
      GO TO (5700,5100,5200), II                                        SHPE 220
 2800 CONTINUE                                                          SHPE 230
      GO TO (5800,6200,5300), II                                        SHPE 240
 5000 SHAPE = TT                                                        SHPE 250
      GO TO 9000                                                        SHPE 260
 5100 SHAPE = .5                                                        SHPE 270
      GO TO 9000                                                        SHPE 280
 5200 SHAPE = (-.35*TT+10.2)/12.                                        SHPE 290
      GO TO 9000                                                        SHPE 300
 5300 SHAPE = .15                                                       SHPE 310
      GO TO 9000                                                        SHPE 320
 5400 SHAPE = 0.                                                        SHPE 330
      GO TO 9000                                                        SHPE 340
 5500 SHAPE = .16*(TT-1.)                                               SHPE 350
      GO TO 9000                                                        SHPE 360
 5600 SHAPE = .8                                                        SHPE 370
      GO TO 9000                                                        SHPE 380
 5700 SHAPE = (-.4*TT+14.4)/12.                                         SHPE 390
      GO TO 9000                                                        SHPE 400
 5800 SHAPE = .4                                                        SHPE 410
      GO TO 9000                                                        SHPE 420
 5900 SHAPE = .2*(TT-1.)                                                SHPE 430
      GO TO 9000                                                        SHPE 440
 6000 SHAPE = 1.                                                        SHPE 450
      GO TO 9000                                                        SHPE 460
 6100 SHAPE = (-.8*TT+21.6)/12.                                         SHPE 470
      GO TO 9000                                                        SHPE 480
 6200 SHAPE = .2                                                        SHPE 490
 9000 RETURN                                                            SHPE 500
      END                                                               SHPE 510
```

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