A NEW DIGITAL ACCELEROGRAPH NETWORK FOR EL SALVADOR

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INTRODUCTION

There are few countries whose geography and history have been so affected by earthquake and volcanic activity as the republic of El Salvador (Fig. 1). The capital, San Salvador, has the unenviable claim of being the Latin American city most frequently damaged by earthquakes Since 1700 San Salvador has been severely damaged by earthquakes on at least 14 occasions (Harlow *et al.* 1993). The last destructive earthquake to affect San Salvador occurred on 10 October 1986, causing about 1,500 deaths and extensive damage over much of the city, as well as causing an economic loss equivalent to 31% of El Salvador's GNP (Coburn and Spence 1992)

El Salvador has been the focus of several studies of seismicity and seismic hazard and the San Salvador earthquake of October 1986 generated renewed interest in the area. Three major hazard studies have produced seismic zonifications of El Salvador and a fourth has been carried out at a regional level in Central America The studies for El Salvador have been carried out by the US Geological Survey (Algermissen *et al.* 1988), Stanford University (Alfaro *et al* 1990) and the Universidad Nacional Autónoma de México (Singh *et al* 1993) The Central American study has been produced as part of the collaborative research effort amongst the Centro de Coordinación para la Prevención de Desastres en América Central (CEPREDENAC), the University of Bergen and NORSAR, (Rojas *et al*, 1993; Lindholm *et al*, 1995). Figure 2 shows the 475-year return-period accelerations presented in the three studies specifically focused on El Salvador. There are very considerable differences in the results obtained: for example, the values for the 475-year return period ground acceleration in San Salvador in these five studies are 0.3, 0.5, 0.76, 1 0 and 1.05*g*. A comparative review of these seismic hazard assessments by Bommer *et al.* (1996) highlights the uncertainties associated with the available seismological and geophysical data, and the necessity of resolving the more important discrepancies before attempting to produce another zonification of El Salvador.

This article introduces an initiative which is attempting to produce a more reliable database from which a seismic hazard assessment for El Salvador will be carried out. Through contacts established during field investigations of the 1986 San Salvador earthquake, a collaborative research project has been established with support from the International Scientific Cooperation program of the Commission of the European Communities. The partner in the research collaboration in El Salvador is the Universidad Centroamericana "José Simeón Cañas" (UCA), the second oldest university in the country, which is run by the Society of Jesus. The project is co-ordinated by the Universidad Complutense de Madrid (UCM), and the other partners are the

Instituto Geográfico Nacional (IGN) in Madrid, Imperial College of Science, Technology and Medicine (ICSTM) in London, the Insitut du Physique de Globe (IPG) and the National Technical University of Athens (NTUA). The project has a total duration of three years and has two broad general objectives: to compile reliable seismological and strong-motion databases in order to determine a new zonification of El Salvador with associated seismic design loads, and simultaneously to establish in the UCA a teaching and research capacity in seismology and earthquake engineering. This second objective is of particular importance since prior to the initial work through which this project was established, there was no formal training in these areas in any of the universities in El Salvador. The project will establish earthquake engineering as a central discipline within the curriculum of civil engineering, which is a vital component of any long-term plan for seismic risk mitigation.

TECTONICS AND SEISMICITY

El Salvador is located on the western edge of the Caribbean plate which overrides the Cocos plate in the Middle America trench, as shown in Fig. 3. The tectonics of the region are complex and in some aspects poorly defined, which is reflected in the differences in the delimitation of seismic sources in the hazard studies referred to earlier. The determination of the maximum magnitude for each seismogenic zone is another source of discrepancy amongst the previous hazard assessments (Bommer *et al.* 1996).

The subduction of the Cocos plate has a velocity of about 7 cm/year and the thrust interface is a major source of earthquake activity, with steep Benioff-Wadati zones descending to about 300 km; the largest instrumentally recorded earthquakes on this interface have had magnitude of about 8 (Dewey and Suarez 1991). Nonetheless, of the 14 earthquakes that have caused destruction in San Salvador since 1700 only five were directly associated with the subduction of the Cocos plate. The most damaging events are the moderate magnitude shallow focus earthquakes that coincide with the chain of Quaternary volcanoes that extends from Guatemala to northern Costa Rica. These events reach magnitudes of about 6.5 and are confined to the upper 20 km of the crust, but their coincidence with major population centres often results in very severe destruction. Occasionally these events are accompanied by volcanic activity, as was the case in San Salvador in 1917 when the Boquerón volcano last erupted, but generally they are tectonic in origin. The volcanic arc seismicity has been interpreted as resulting from a right-lateral shear zone driven by an oblique component of convergence between the Caribbean and Cocos plates (White 1991). A particular problem associated with the characterization of the seismicity in El Salvador is the reliable determination of focal depths, which in some cases has led to association of volcanic chain events with the Benioff zones, such as in the case of the earthquakes that destroyed the towns of Jucuapa and Chinameca in eastern El Salvador in May 1951. Macroseismic evidence strongly suggests that these events were of upper crustal origin (Meyer-Abich 1952; White and Harlow 1993), but in seismological catalogues the depths are reported as 90 to 120 km.

Another important source of earthquake activity that can affect El Salvador is the boundary between the Caribbean and North American plates that forms a left-lateral transform zone on the Chixoy-Polochic and Motagua faults that pass through Guatemala. Nonetheless, the incidence of this remote source in the hazard level in El Salvador is unlikely to be high; the magnitude 7.5 earthquake that occurred in Guatemala in February 1976 was felt with MM intensity V in El

Salvador (Espinosa 1976)

El Salvador could also be affected by seismic activity in two intraplate sources to the north: one is the Honduran Depression where some historical earthquakes have been reported to reach magnitude 6 or 6½ (Sutch Osiecki 1981), and the other is an area of extensional tectonics bounded by the Motagua fault, the volcanic chain and the Honduran Depression where earthquakes in the eighteenth century are reported to have occurred with magnitude greater than 7 (White 1991).

STRONG-MOTION DATABASE

The comparative review of hazard studies carried out for El Salvador (Bommer *et al.* 1996) has revealed, rather surprisingly, that the attenuation relations for peak acceleration employed in the different studies are quite similar and the differences between the predicted values is not sufficient to explain the very significant divergence amongst the results. Nonetheless, all of the attenuation equations have been based on rather limited and heterogeneous datasets, which include recordings of both upper-crustal earthquakes in the volcanic chain region and events associated directly with the subduction zone. One recent study of strong-motion attenuation characteristics in Central America (Dahle *et al.* 1995), using a dataset of 280 triaxial accelerograms from throughout Central America and from the Guerrero array in Mexico, concluded that there is not a significant difference between the attenuation characteristics of the two types of events. Nonetheless, the intensity distribution of Central American earthquakes suggests that there are differences, which in part are obscured by other factors that affect the strong-motion recordings, particularly the soil response. One aspect of the current research project is the investigation of differences between the recordings from subduction earthquakes and from shallow crustal earthquakes. Figure 4 shows recordings obtained in San Salvador of each of these types of earthquake: the first corresponds to a magnitude M_s 7.3 subcrustal (h = 80 km) event in the subduction zone on 19 June 1982, which caused moderate damage in many parts of the country (Alvarez 1982), recorded at an epicentral distance of about 50 km. The second recording was obtained at about six kilometres distance from the shallow focus magnitude M_s=5.4 earthquake of 10 October 1986. The response spectra are not shown because these records are from different stations and it would be difficult to decouple source and site effects.

In order to assess the priorities for the deployment of the new accelerograph network, a database of strong-motion records from Central America has been compiled from various sources. Obviously there is no justification for limiting the study of strong-motion characteristics in the region to El Salvador and records have been included from surrounding areas which are geologically similar. This area includes Guatemala, Honduras and northern Nicaragua as far south as the Lago de Nicaragua, as well as El Salvador, which consists of continental type crust with Paleozoic or even older metamorphic rocks. These are overlain by sediments which were deformed after the Middle Permian and between the Cretaceous and Tertiary. Northern Central America was subjected to very violent continental volcanism during the Tertiary, during which large masses of ignimbrite were extruded. Southern Central America, including southern Nicaragua, Costa Rica and Panamá, on the other hand, consists mainly of oceanic type crust, over which marine sediments and volcanics were deposited during the Tertirary, converting the crust to its present transitional state between oceanic and continental (Weyl 1980). In view of the different attenuation characteristics that might be expected as a result of the different geological histories and structures, only records from Northern Central America are considered herein.

The database of strong-motion recordings has been identified for northern Central America from a large number of sources, and those accelerograms for which the minimum necessary information is available are presented in the Appendix. The seismological parameters for these recordings have been selected from the earthquake catalogue that is being developed within the framework of this research project. Figure 5 shows the distribution of this dataset in magnitude-distance space, including an indication of which records are associated with subduction events.

Although an appreciable body of data has been collected and several of the records have been digitized, there are a number of deficiencies in the distribution of the recordings that need to be addressed. If the strong-motion database is separated according to the seismic source of the generating earthquakes, it is apparent that the number of recordings from volcanic chain events is relatively small. Moreover, the distribution of this data with respect to magnitude and distance is poor, with nearly all the records obtained at epicentral distances of no more than a few kilometres from moderate earthquakes. As a result it is difficult to obtain a reliable estimate of the attenuation characteristics for volcanic chain earthquakes from the available data set.

NEW DIGITAL NETWORK

A network of SMA-1 analogue accelerographs is operated in El Salvador by the Centro de Investigaciones Geotecnicas (CIG), which is run by the Ministry of Public Works. This network currently consists of 16 accelerographs distributed throughout El Salvador: four are located within San Salvador in the UCA, the CIG, the Observatorio Sismológico and in Soyapango, and the others dispersed throughout the country in Acajutla, Ahuachapán, Chalatenango, Comalapa (airport), Cutuco, Metapán, San Miguel, Santa Ana, Santa Tecla, Santiago de María, San Vicente and Sensuntepeque, as shown in Figure 6. In addition to these instruments, another eight have been installed as a three-dimensional array within San Salvador, with instruments at ground level and at the bottom of four wells.

Three SMA-1 strong-motion accelerographs are also operated by the Comisión Ejecutiva Hidroeléctrica del Rio Lempa (CEL) on the San Lorenzo (15 de spetiembre) Dam on the Lempa River. Two SSA-2 accelerographs have also been installed recently as part of a monitoring network around the geothermal plant recently initiated in Berlín. Three SMA-1 instruments are also operated by the Camino Real Hotel in San Salvador, apparently the only large building to have fulfilled Article 30 of the 1966 Regulations for Seismic Design that specified that strong-motion instruments should be installed in all buildings with an area exceeding 10,000 m^2 or height greater than 45 m. These instruments recorded the ground motion and structural response of the October 1986 earthquake (Shakal *et al.* 1987).

The new strong-motion network established within this project consists of ten Kinemetrics SSA-2 digital accelerographs. These have been deployed to provide coverage of seismicity from both the volcanic chain zone and the subduction zone. At the same time, the network is designed to cover different surface geologies in central and southern El Salvador. Given that a significant number of records have already been obtained in San Salvador and that the CIG network gives good coverage of the metropolitan area, it was decided to install only one instrument within the capital. For the areas outside San Salvador, it was necessary to identify a large number of possible sites, preferably under the direction and management of a single organization, which could provide secure locations for the stations. An ideal solution was found through the establishment of an agreement with the Ministerio de Salud Pública y Asistencia Social, which gave access to hospitals and health units throughout El Salvador. The agreement was fomented by the Disasters Unit of the Health Ministry and part of the agreement is that the UCA will undertake evaluations of the seismic vulnerability of some of the health care establishments.

Priority was given to hospitals rather than health centres because of the better infrastructure and greater security that they can provide. The locations were also chosen to enable reasonably easy access for maintenance of the instruments and data recovery, since despite its small geographical extent, travel in El Salvador is often difficult and time consuming. The network was designed according to these criteria in order to cover three important sources of seismic activity in the volcanic-chain zone: San Salvador and Lake Ilopango, the area south-east of Lake Coatepeque to the west of San Salvador and San Vicente to the east of San Salvador. Stations have also been located to the south as far as the coast, and a single station has been placed to the north of San Salvador The distribution provides coverage of both the subduction zone and the volcanic chain, and in particular will allow recording of volcanic chain earthquakes close to the source and at distances of the order of 10 to 50 kilometres, which will help to resolve the uncertainty associated with the attenuation of strong motion from shallow crustal events. The distribution of the network is shown in Figure 6. The locations are presented in the table below, the co-ordinates have been measured using portable GPS and the elevations correspond to the closest geodesic benchmarks of the Salvadorean Instituto Geográfico Nacional (IGN). All of the instruments are installed at ground level.

In all the stations, the instruments have been set to trigger with an acceleration level of 0.010g horizontally or 0.006g vertically. The pre-event memory of 10 seconds and the post-event memory as 15 seconds, with full-scale set to record a maximum acceleration equal to 1.0g.

The UCA manufactured shelters for each of the accelerographs after several non-seismic events were found when the first recordings were recovered! These shelters have dimensions of 50 cm x 40 cm x 45 cm and have been made from ceiling material (*Fibrolit*) reinforced with a wooden beam around the base.

At this stage, detailed information about site conditions are not known, although this information is being recovered from a number of sources, including a few borehole logs available for the actual station sites as well as the logs from water wells drilled by the Administración Nacional de Acueductos y Alcantarrillados (ANDA), several of which are close to the accelerograph stations. This information will be presented in full in the first three monthly report on the operation of the network It is important to extraploate such information with caution since the topography of El Salvador is such that a great deal of construction involves extensive use of landfill, particular to reclaim steep ravines. The general geological characteristics of the sites presented here are as interpretted from the 1:100,000 geological maps of El Salvador prepared by the Geological Mission of the Bundesantalt für Bodenforschung, Hannover, Germany, and published in 1978 by the IGN in El Salvador. Descriptions of the different formations are also presented by Schmidt-Thomé (1975), Weyl (1980) and Baxter (1984). Some of the sites are therefore classified as rock even though there may well be soil cover.

Code S/n	Location	Coordinates Elevation (m)	Type of structure
ESJO 2396	Externado de San José San Salvador	13.708°N 89.207°W 675	Library of secondary school. One-storey annex of two-storey RC frame with masonry walls
UARM 2404	Unidad de Salud Armenia, Sonsonate	13 668°N 89.505°W 570	Storage room in health centre, one-storey building of RC frame and brick walls, light roof.
HSRF 2397	Hospital San Rafael Santa Tecla La Libertad	13.671°N 89.278°W 912	Large hospital warehouse. Single storey construction with RC columns.
ULLB 2398	Unidad de Salud La Libertad	13.486°N 89.327°W 16	Storage room in health centre, one-storey building of RC frame and brick walls, light roof.
UPAN 2401	Unidad de Salud Panchimalco San Salvador	13.613°N 89.179°W 613	Administration office in one-storey building of RC frame and brick masonry walls.
HSTR 2402	Hospital Santa Teresa Zacatecoluca, La Paz	13.518°N 88.868°W 253	Single storey annex of RC and brick masonry adjacent to 5-storey RC frame building
USPN 2399	Unidad de Salud San Pedro Nonualco La Paz	13.601°N 88.928°W 658	Storage room in health centre, one-storey building of RC frame and brick walls, light roof
HSGT 2403	Hospital Santa Gertrudis San Vicente	13.642°N 88.784°W 373	Storage room in health centre, one-storey building of RC frame and brick walls, light roof.
CSBR 2395	Centro de Salud San Bartolo San Salvador	13.705°N 89.106°W 622	Storage room in health centre, one-storey building of RC frame, hollow brick walls, light roof
UTON* 2400	Unidad de Salud Tonacatepeque San Salvador	13.778°N 89.111°W 607	Storage room in health centre, one-storey building of RC frame and brick walls, light roof.

* UTON station to be installed in August 1996, due to relocation of Health Centre and technical problems with the accelerograph.

El Salvador consists of four morphological-geological units which exist as apprxomiately parallel strips running east-west across the country (Weyl 1980). Along the border with Honduras are the northern mountain ranges, consisting mainly of plutonic rocks from the Tertiary. There is no evidence of serious earthquake damage in this part of the country and none of the instruments are located in this area. The central part of El Salvador is the Great Interior Valley, a heterogeneous basin and low mountain topography; the southern part of the Valley contains the chain of Pleistocene volcanoes, six of which are active. Nearly all of the major cities of El Salvador, and hence most of the population, are located within the Great Interior Valley. To the south of the Valley there are three coastal mountain ranges: the Tacuba in the west on the border with Guatemala, the Balsamo in the central and western area and the Jucuarán range on the estern side bordering the Golfo de Fonseca. In between the coastal ranges are the coastal plains in the western and central parts of the country which consist of alluvial deposits with intercalated pyroclastics, spits and mangrove swamps.

The UTON station is located within the Great Interior Valley to the north of the axis of the volcanic chain, whereas the ESJO, CSBR and HSGR stations are located along the volcanic chain. The surface geology at these four sites is *tierra blanca*, a young, poorly consolidated, volcanic tuff which originated from eruptions within Lake Ilopango during the Holocene.

The station UARM is located on the boundary between the Great Interior Valley and the Balsamo range and it is also overlain by Holocene volcanic tuff known as *tobas color café*, which is slightly older than the *tierra blanca*.

The HSRF station is also situated on the boundary between the Great Interior Valley and the Balsamo range, but in an area of effusive rocks from the Late Pleistocene, which together with the *tierra blanca* and the *tobas color café* consitute the San Salvador formation which is the most recent in the country.

The stations USPN and UPAN are located within the Balsamo range, the former on the northern side close to the volcanic centre of Chichontepeque and the latter on the southern side where the mountains descend to the coastal plain. The geology at these two sites consists of pyroclastics and volcanic rocks which belong to the Cuscatlán formation associated with acidic and intermediate volcanism during the Pleistocene which produced ignimbrites on the southern slopes of the Balsamo range.

The HSRT station is located in the costal plain on the older Balsamo formation, Tertiary pyroclastics and volcanic rocks, which in many locations are overlain by thick covers of red soils

The station ULLB is located on the coast to the south of the Balsamo range on Quaternary sedimentary deposits which are part of the San Salvador formation.

In the light of the lack of agreement on the classification of site conditions in attenuation studies and the preliminary nature of this data, no attempt is made to classify the sites as 'rock' or 'soil' until further investigations have been carried out.

PRELIMINARY RESULTS

The new accelerograph network was tested almost immediately after installation by an earthquake that occurred on 3 March 1996, two days after the last instrument had been placed in Panchimalco. The earthquake occurred off the coast of Nicaragua at 16:37:26 UTC with a location reported by NEIC as 11.1°N, 86.7°W and of normal depth, and the magnitude is reported as M_s 6.6. This was really an ideal event with which to initialize the operation of the network, since the azimuth from the source of all the stations is almost equal and the distances are comparable, so the main source of differences in the recordings will be mainly due to site characteristics. In this sense, the earthquake serves to some extent to calibrate the network.

Of the nine stations operational at the time of the earthquake four were triggered: UARM, HSTR, USPN and HSGT. The five stations that did not trigger were all checked and found to be functioning identically to those that triggered, with the exception of ESJO, which at the time had been initially set with the trigger characteristics of an SMA-1 (0.01*g* vertical acceleration). The station USPN also recorded a smaller event that occurred about an hour an a half earlier at 14:55 UTC, located in the same general area and for which the NEIC reports a magnitude of M_s 6.4, which was also widely felt throughout south and eastern El Salvador. As a result of initial problems with the GPS apparatus only UARM had absolute time recording at the time of the earthquake. The characteristics and peak values of these first five records are presented in the table below.

Earthquake	Station	Dist	Acc (g)			Vel (cm/s)		
		(km)	N-S	E-W	Vert	N-S	E-W	Vert
3/3/96 14:55	USPN	368*	0.011	0.008	0.006	0.6	0.5	0.3
3/3/96 16:37	HSTR	357	0.009	0.010	0.010	0.8	1.0	0.5
	HSGT	361	0.013	0.016	0.009	1.6	1.3	0.7
	USPN	368	0.023	0.021	0.013	1.6	1.4	0.9
	UARM	417	0.012	0.011	0.008	1.0	0.9	0.4

* Assuming same epicentral location as for mainshock.

Figure 7 shows the four main shock acceleration time histories. The horizontal acceleration response spectra at 5% of critical damping are shown in Figure 8 for each of the records; in Fig. 8(d) the spectra of the main shock and foreshock at USPN are plotted on the same axes. Apart from the peak at around 0.7 seconds on the spectra from UARM, HSGT and HSTR, which may be a source feature, there are few common characteristics amongst the spectra which suggests that they do reflect site effects. This is also confirmed by two records from USPN, for which the foreshock and mainshock spectra are very similar in shape.

It is interesting to examine these recordings to see if they can reveal any information regrading the site characteristics of the stations, keeping in mind that the response may be quite different for stronger shaking caused by closer earthquakes. The ratios of velocity to acceleration (v/a) were used by Seed *et al.* (1976) to characterize site conditions, and they concluded that values of about 66 cm/sec/*g* were representative of bedrock, with 114 cm/sec/*g* for stiff soil sites and 140 cm/sec/*g* for deep cohesionless soils. The average values from both the foreshock and the mainshock suggest that USPN is a rock site, even though it may be overlain by thin layer of soil.

The values for the other stations implies that they are stiff soil, although the data Seed *et al.* (1976) employed were all from much shorter distances and the general trend they found was for a reduction of the (v/a) value with increasing distance for soil sites.

The final exercise has been to employ the spectral ratio method used by Theodulidis and Bard (1995), plotting the ratio of horizontal to vertical amplitudes of the Fourier spectra as a function of frequency. The method is based on the assumption that the horizontal motion may be amplified by the presence of soil layers but that vertical motion is not, hence the ratio of the two should represent the influence of the soil layers or other sites effects. The ratios of the spectra were found for the time-histories in Fig. 7 and smoothed by between 100 and 150 passes of a three-point running average, and the plots are shown in Fig. 9. It would be unwise to draw too many conclusions from these single recordings, given that the source characteristics have an even more pronounced effect on the spectral shape than the site conditions in some cases (Singh 1985), but a number of observations may be made Firstly, nearly all of the records display a peak at about 0.5 Hz, which would appear therefore to be a source effect, even though it is not visible on the response spectra in Fig. 8. The UARM record displays a strong peak around 1.8 Hz, which would correspond to a site period of 0.56 seconds. The HSGT records display a number of peaks, including at about 1.2, 3.6 and 4.7 Hz; a borehole log from this site shows a 3-3.5 m layer of sndy silts and clays and silty sands at the site, and the higher peaks could correspond to the response of these deposits. The HSTR record shows a clear peak at 7.7 Hz as well as smaller peaks 1.5 and 3.5 Hz. The USPN record shows some smaller peaks at frequencies above about 5 Hz, which could reflect a thin soil layer, but there is also an exceptional narrow peak at 2.7 Hz. This sharp peak is also seen in the record of the foreshock obtained at the same station, which is shown in Figure 10 The USPN station is located atop a narrow and elongated ridge and it is highly probable that the apparent amplification of motion at this site is mainly due to topographical effects. As further records are obtained, these characteristics will be explored further.

FUTURE WORK

The areas of research that are covered by the project are mainly directed towards a re-evaluation of the seismicity of El Salvador and surrounding areas and the attenuation characteristics of strong-motion in the region. A major component of the work is a thorough re-evaluation of instrumental and historical earthquakes, including re-locations (Ambraseys and Adams 1994, 1996) and re-evaluation of magnitudes (Ambraseys 1995; Ambraseys and Adams 1996). The associated parameters for the existing strong-motion recordings are also being re-evaluated and together with new recordings obtained, the attenuation characteristics of peak acceleration and spectral ordinates will be explored.

In parallel with these investigations, the application of different methods of hazard analysis are being explored and sensitivity studies of the hazard assessments are being carried out. This includes exploring separate zonations for seismic hazard associated with the subduction zone and with the volcanic chain, as was originally proposed by Rosenblueth (1965). For the volcanic chain zone seismicity, at least for San Salvador, it is debatable if a 475-year return period earthquake has much meaning in an area where damaging earthquakes occur on average every 23 years (Harlow *et al.* 1993).

The project will also include preliminary assessments of secondary seismic hazards, particularly the amplification of ground motion by soil deposits, which has been the focus of several studies for San Salvador (Rymer 1987; Faccioli *et al.* 1988; Atakan and Torres, 1994), and also landslides (Rymer and White 1989) and tsunamis. Data is also being collected on building stock and damage patterns in previous earthquakes in order to develop a preliminary seismic risk model.

An important activity that has been organized within the framework of the current research project is a Seminar on Assessment and Mitigation of Seismic Risk in the Central American Area. There is a great deal of research underway in Central America in the areas of seismic hazard and risk and important projects have been undertaken to mitigate the potential for future disasters. The objective of the seminar is to bring together those working on all aspects of seismic risk mitigation in order to facilitate an exchange of ideas and experiences and to promote co-operation in specific areas. Apart from the participants in the project, the seminar is supported by the Centre for the Coordination of the Prevention of Natural Disasters in Central America (CEPREDENAC), the Latin American and Caribbean Office of the International Decade for Natural Disaster Reduction (IDNDR), the Panamerican Health Organization (OPS), the International Association of Earthquake Engineering (IAEE), the International Association of Seismology and Physics of the Earth's Interior (IASPEI), the Universidad de Costa Rica, the Universidad Nacional de Costa Rica, the Universidad de El Salvador and NORSAR. The Seminar will take place in San Salvador during the week 22-27 September 1997. Papers are invited on any of the following topics, provided that they refer specifically to the Central American area: tectonics and seismicity; recording and prediction of strong motion; seismic hazard assessment; seismic zoning and microzonification; reports of destructive earthquakes; assessment of vulnerability and seismic risk; codes for earthquake-resistant design; repair and strengthening of existing structures; seismic protection of monuments; seismic risk mitigation in planning; insurance against earthquake damage and preparation of emergency measures. Further information regarding the Seminar and registration forms can be obtained from: Ing. Patricia Méndez de Hasbun, Departamento de Ingeniería Civil, Universidad Centroamericana "J S. Cañas", Apartado Postal (01) 168, San Salvador, El Salvador. Fax: +503-273-8140/273-1010. E-Mail enquiries may be directed to j.bommer@ic.ac.uk.

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LIST OF FIGURES

LIST OF PLATES

[There are a number of good slides showing the locations of the instruments and two or three of these will be submitted with the final version of the report.]

APPENDIX

Strong-motion records from northern Central America

[outstanding]

FIGURE 2

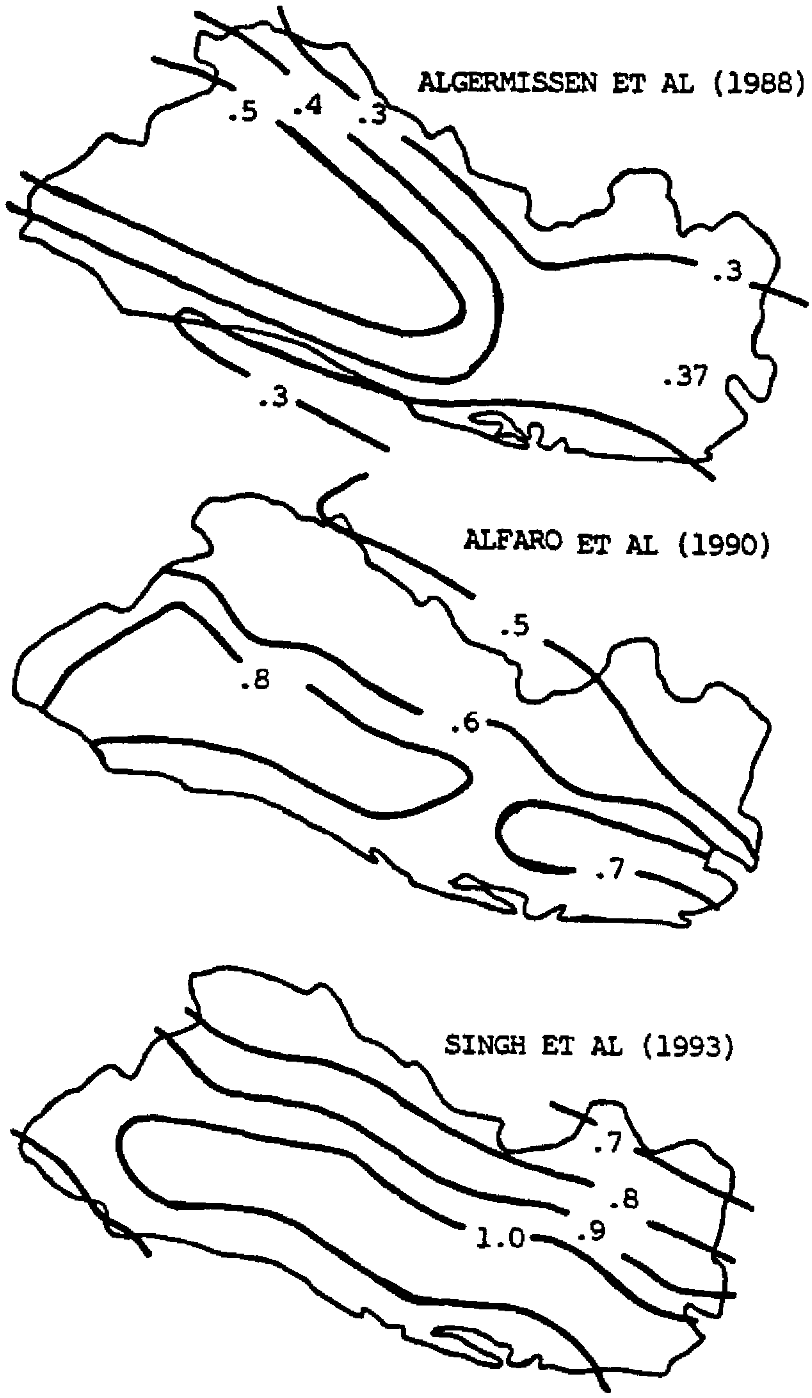


FIGURE 3

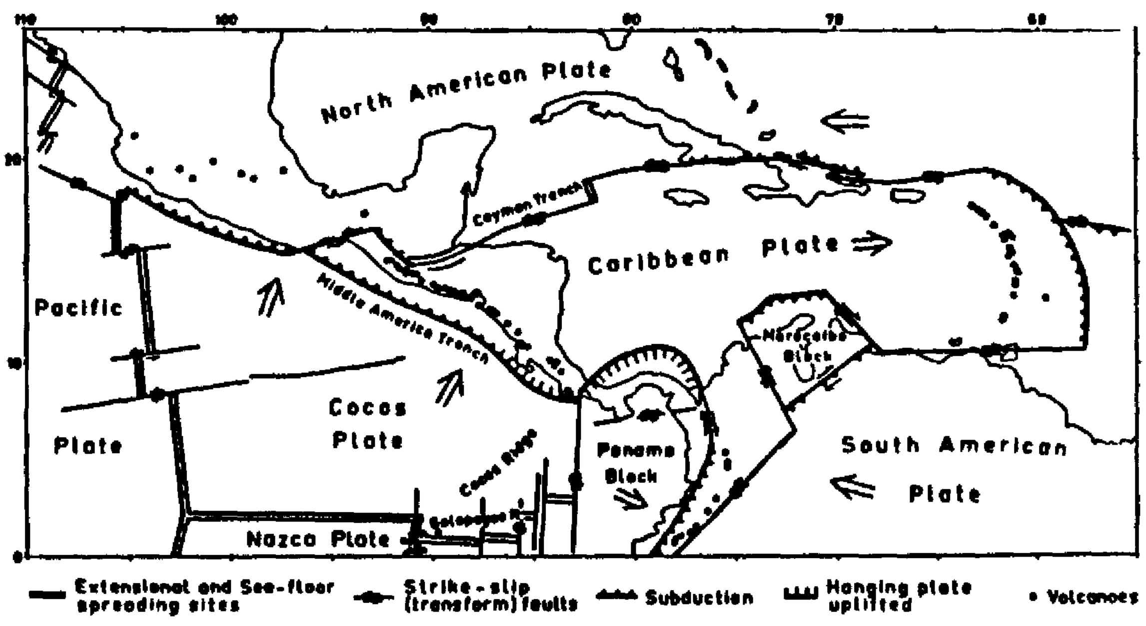


FIGURE 4

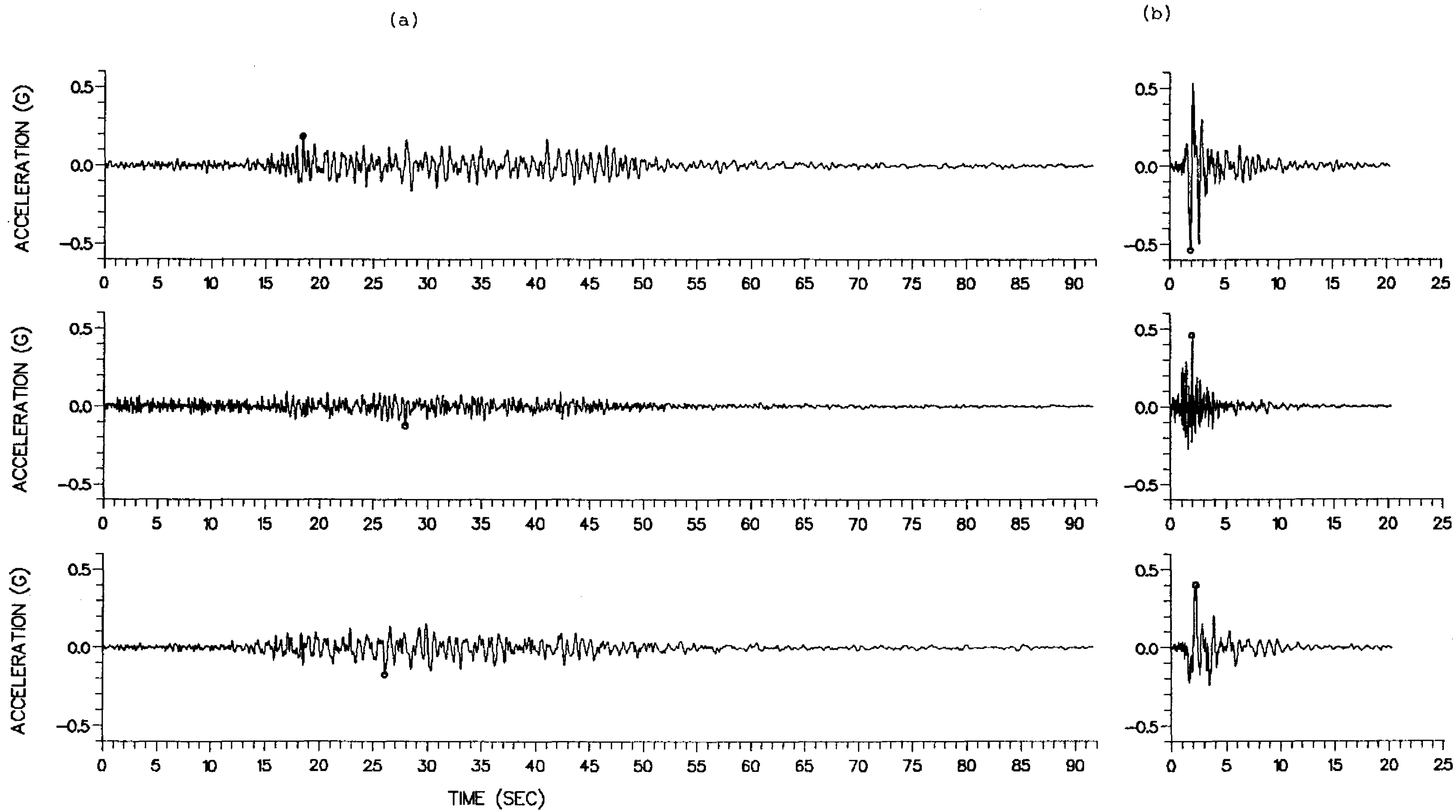

(a)
(b)
ACCELERATION (G)
0.5
0.0
-0.5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
TIME (SEC)

FIGURE 7 (a)

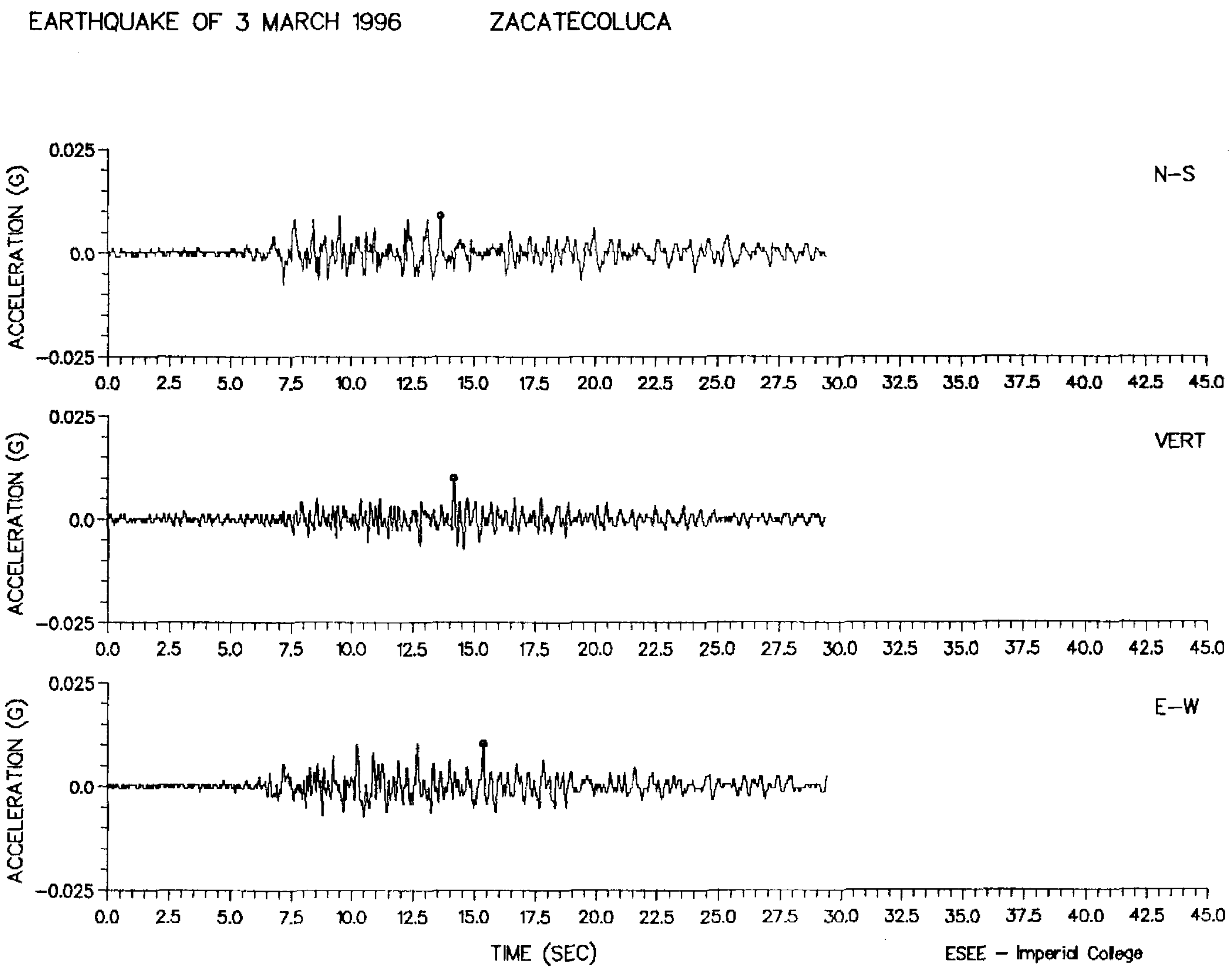

EARTHQUAKE OF 3 MARCH 1996
ZACATECOLUCA
ACCELERATION (G)
0.025
0.0
-0.025
N-S
VERT
E-W
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
27.5
30.0
32.5
35.0
37.5
40.0
42.5
45.0
TIME (SEC)
ESEE – Imperial College

FIGURE 7 (b)

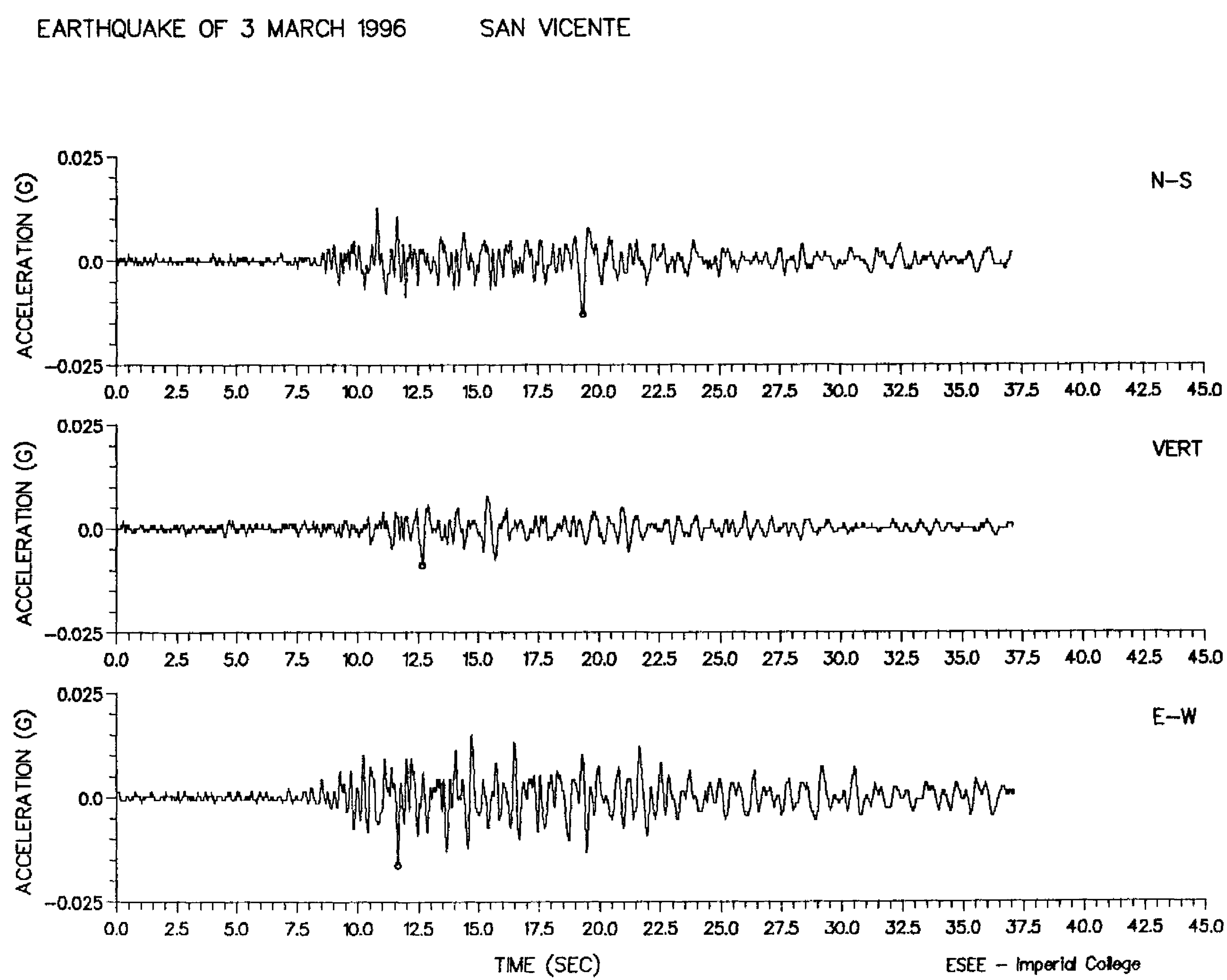

EARTHQUAKE OF 3 MARCH 1996
SAN VICENTE
N-S
VERT
E-W
ACCELERATION (G)
0.025
0.0
-0.025
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
27.5
30.0
32.5
35.0
37.5
40.0
42.5
45.0
TIME (SEC)
ESEE - Imperial College

FIGURE 7 (c)

EARTHQUAKE OF 3 MARCH 1996 ARMENIA

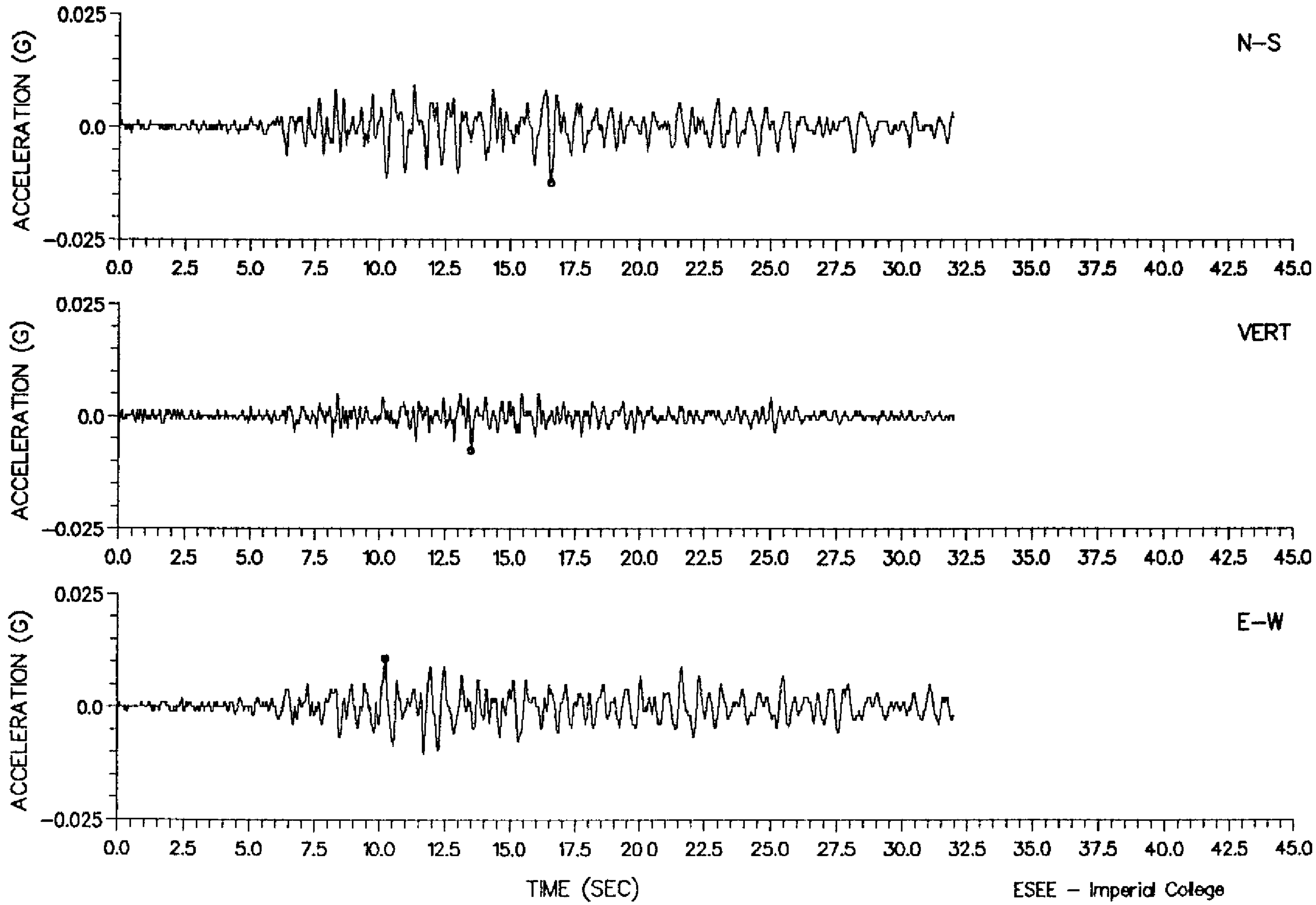


FIGURE 7 (d)

EARTHQUAKE OF 3 MARCH 1996 SAN PEDRO NONUALCO

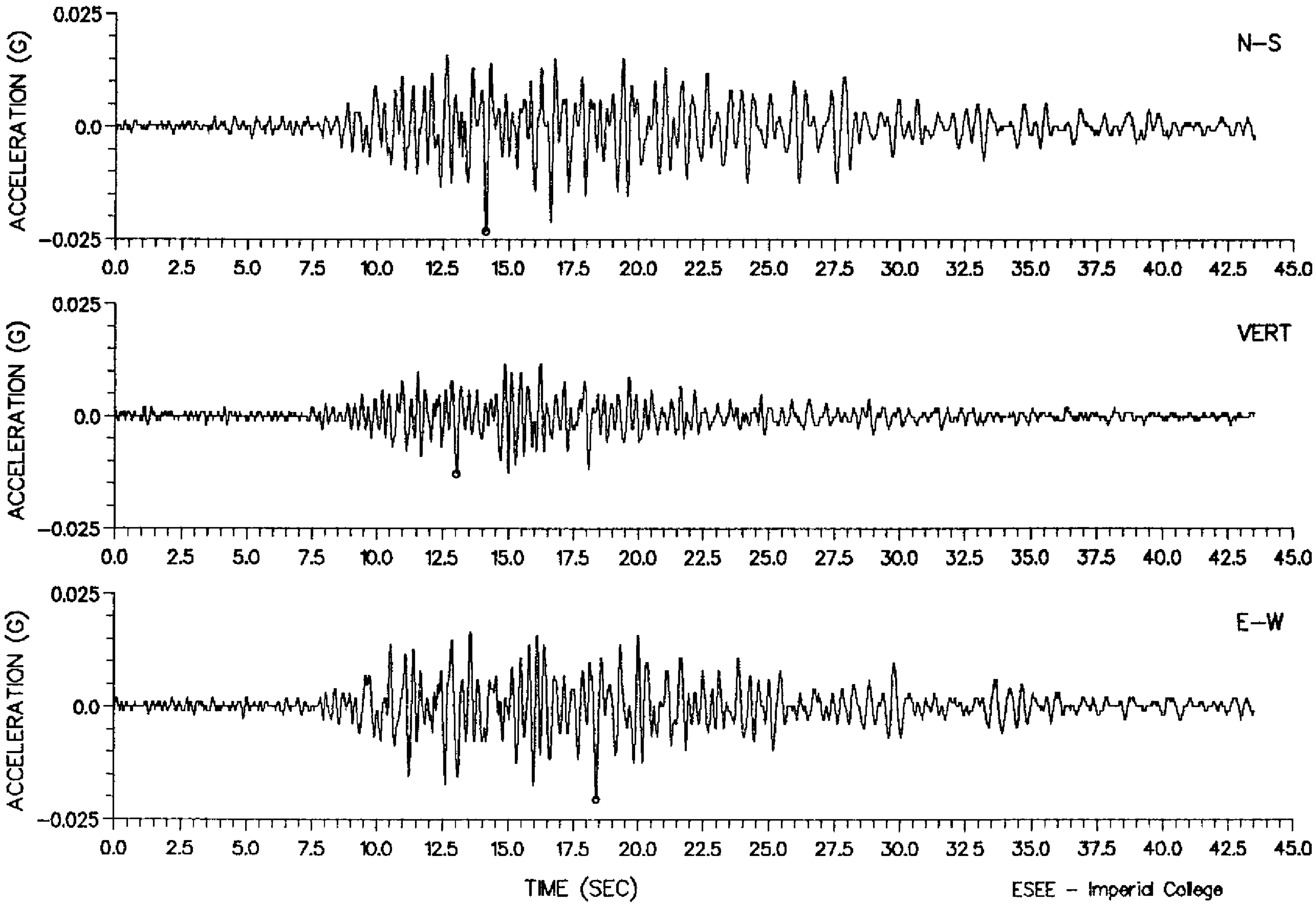


FIGURE 8

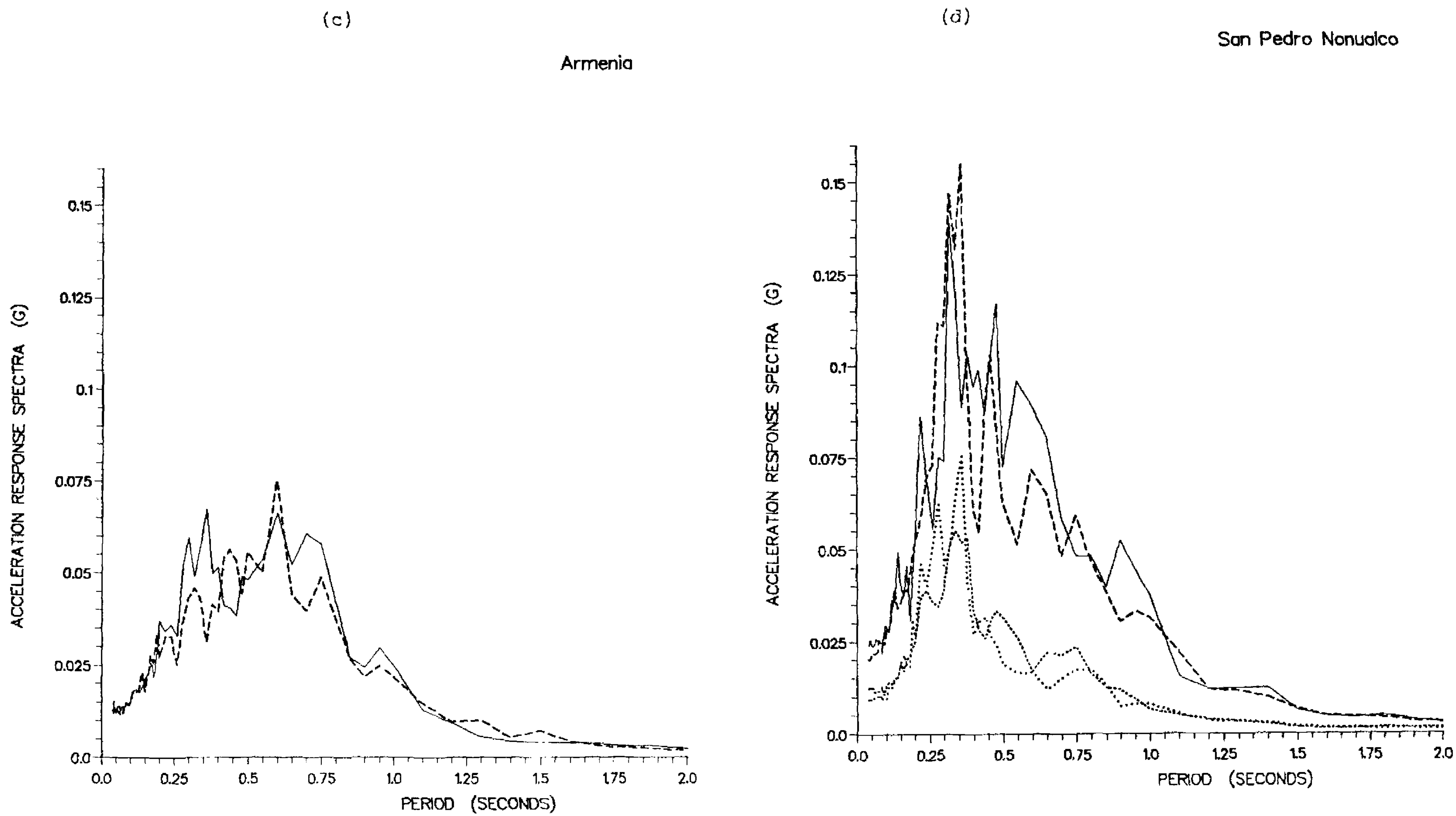

(c)
Armenia
ACCELERATION RESPONSE SPECTRA (G)
0.0
0.025
0.05
0.075
0.1
0.125
0.15
0.0
0.25
0.5
0.75
1.0
1.25
1.5
1.75
2.0
PERIOD (SECONDS)
(d)
San Pedro Nonualco
ACCELERATION RESPONSE SPECTRA (G)
0.0
0.025
0.05
0.075
0.1
0.125
0.15
0.0
0.25
0.5
0.75
1.0
1.25
1.5
1.75
2.0
PERIOD (SECONDS)

FIGURE 9

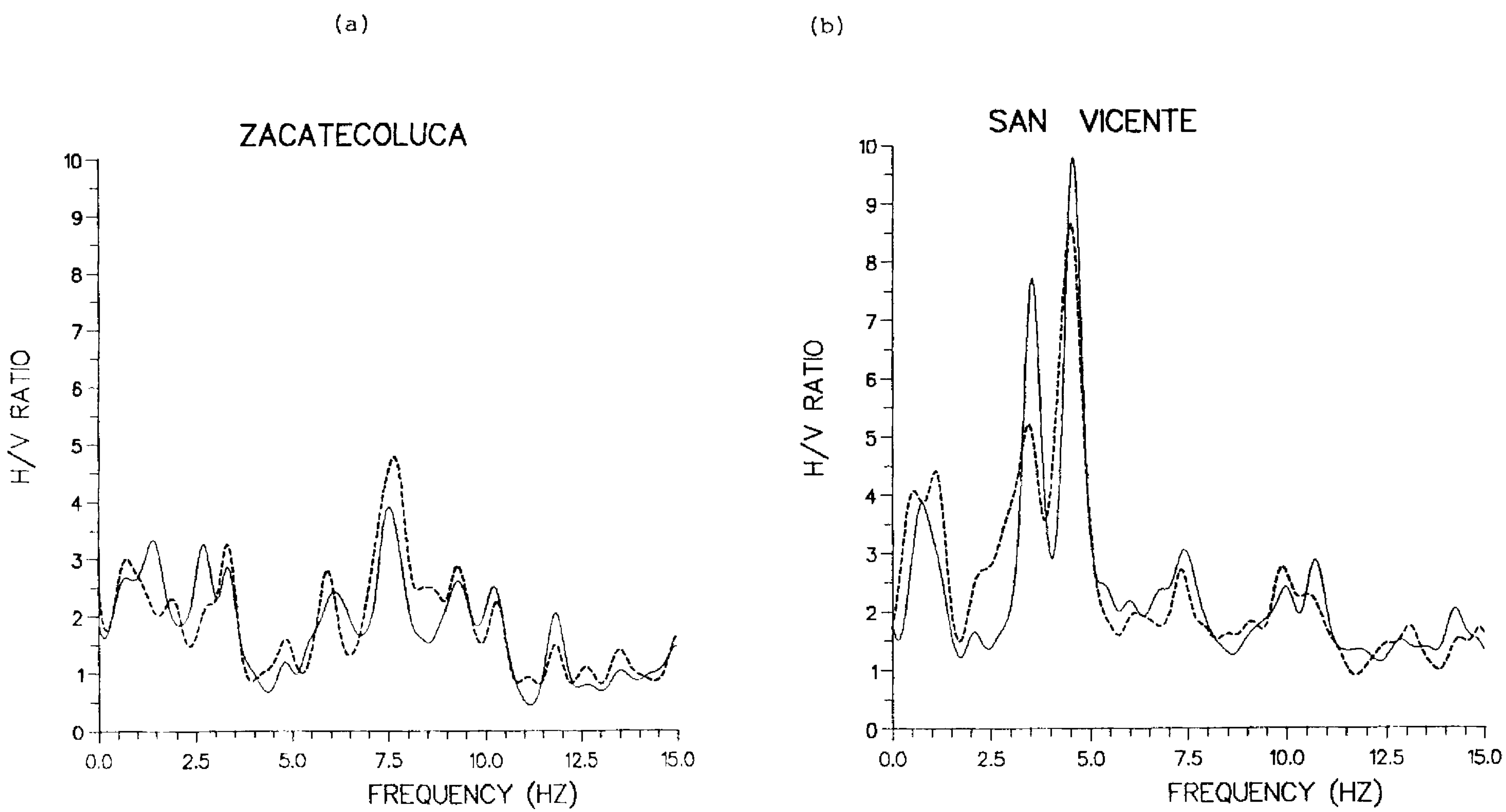
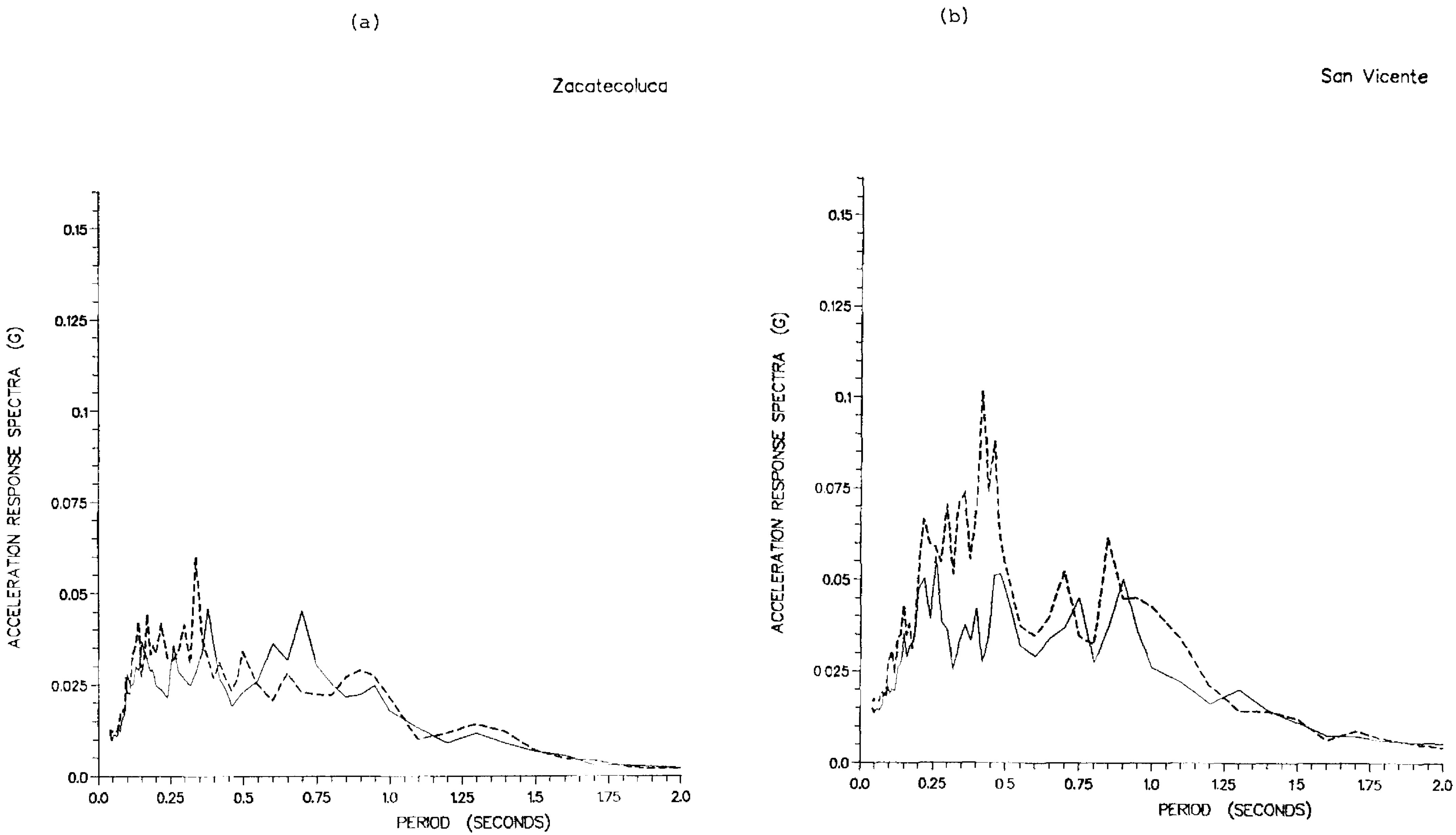

(a)
(b)
ZACATECOLUCA
SAN VICENTE
H/V RATIO
FREQUENCY (HZ)
0
1
2
3
4
5
6
7
8
9
10
0.0
2.5
5.0
7.5
10.0
12.5
15.0

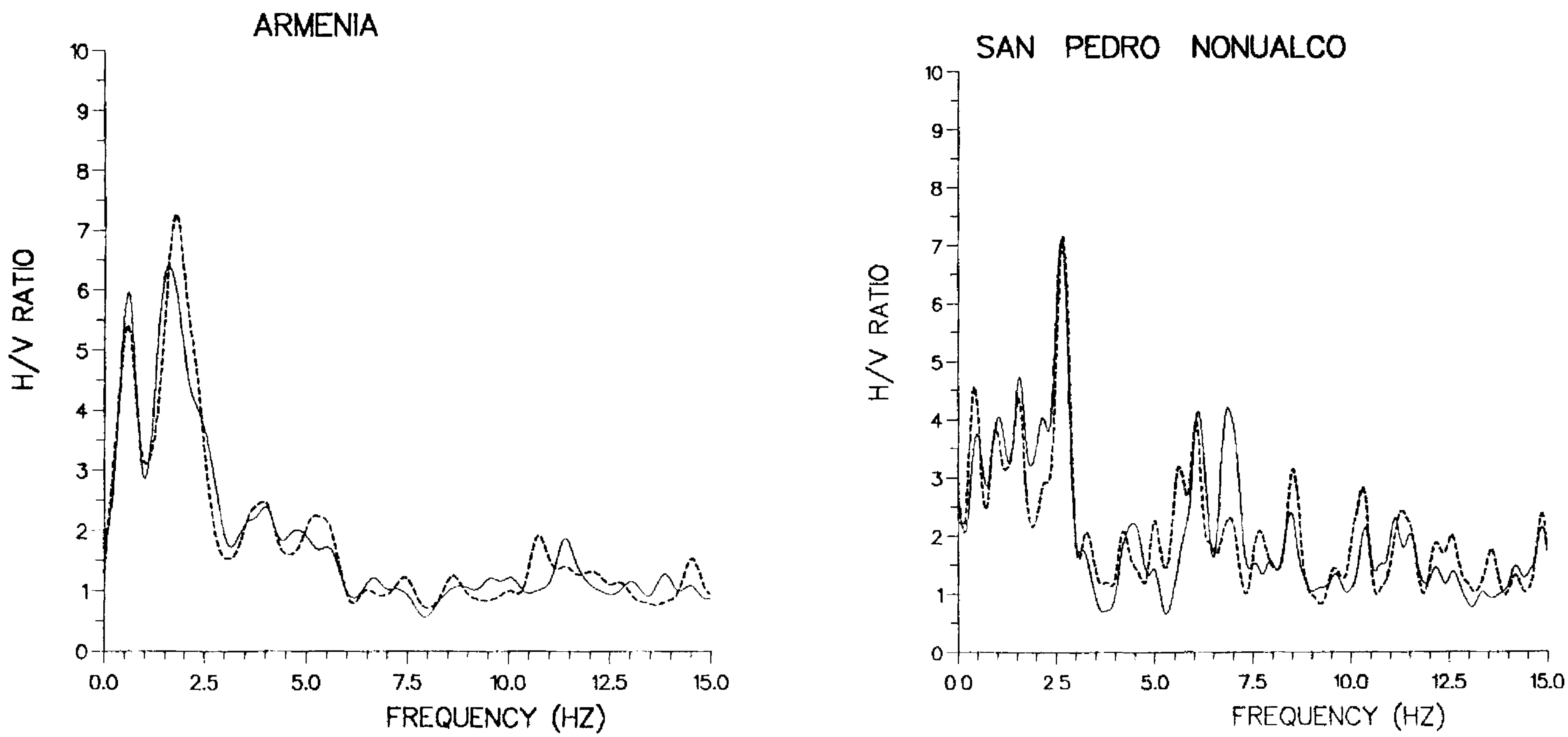
FIGURE 8



(a)
Zacatecoluca
ACCELERATION RESPONSE SPECTRA (G)
0.0
0.025
0.05
0.075
0.1
0.125
0.15
0.0
0.25
0.5
0.75
1.0
1.25
1.5
1.75
2.0
PERIOD (SECONDS)
(b)
San Vicente
ACCELERATION RESPONSE SPECTRA (G)
0.0
0.025
0.05
0.075
0.1
0.125
0.15
0.0
0.25
0.5
0.75
1.0
1.25
1.5
1.75
2.0
PERIOD (SECONDS)

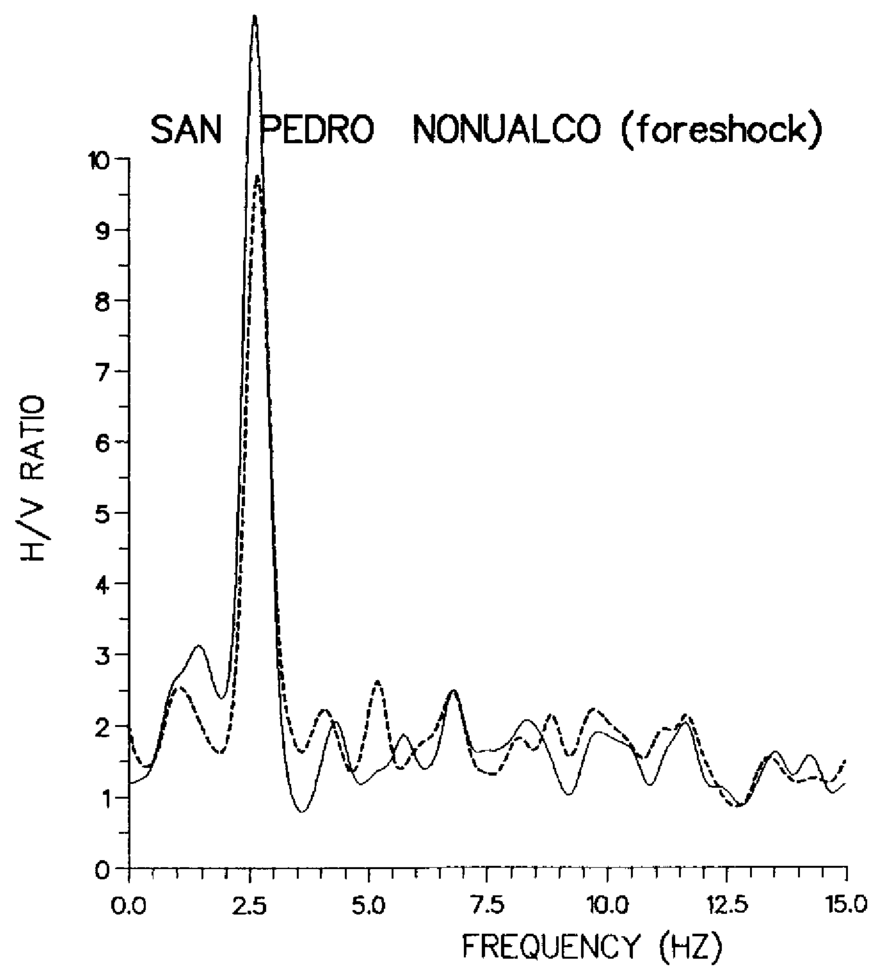
FIGURE 9

(c) (d)



ARMENIA
H/V RATIO
FREQUENCY (HZ)
SAN PEDRO NONUALCO
H/V RATIO
FREQUENCY (HZ)

FIGURE 10



SAN PEDRO NONUALCO (foreshock)
H/V RATIO
FREQUENCY (HZ)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
0
1
2
3
4
5
6
7
8
9
10