The John A. Blume Earthquake Engineering Center

Department of Civil Engineering
Stanford University

11/6/78

A BAYESIAN APPROACH TO SEISMIC HAZARD MAPPING; DEVELOPMENT OF STABLE DESIGN PARAMETERS

by
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This research was partially supported by
Organisme de Contrôle
Technique de la Construction
Algiers, Algeria
and by The John A. Blume
Earthquake Engineering Center
Department of Civil Engineering
Stanford University
Stanford, California

Report No. 28
March 1978

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50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. NSF/RA-780321	2.	3. Recipient's Accession No. PB290374

4. Title and Subtitle Bayesian Approach to Seismic Hazard Mapping, Development of Stable Design Parameters	5. Report Date March 1978 6.
7. Author(s) C.P. Mortgat, H.C. Shah	8. Performing Organization Rept. No. 28
9. Performing Organization Name and Address Stanford University Department of Civil Engineering John A. Blume Earthquake Engineering Center Stanford, California 94305	10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address Applied Science and Research Applications (ASRA) National Science Foundation 1800 G Street, N.W. Washington, DC 20550	13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

The Bayesian procedure, developed in this research and applied as a case study to Nicaragua, has the advantage of combining all the available historical, seismological and geological information in a rational and consistent way. The mapping parameters considered for this study are the peak ground acceleration and the duration of the strong ground motion. In order to be consistent with the probabilistic approach of the model and to take into consideration the large scatter for attenuation data, probabilistic treatment of the attenuation relationships in the form of coefficient of variation is presented. Comparison is made between the iso-acceleration maps developed in this study and previous results. An in-depth numerical study of 97 accelerograms is also presented in this report. This numerical study was conducted to better understand the statistical behavior of input accelerograms and response time histories and to develop better design parameters for use by engineers. Various possible applications and uses of the parameters developed are suggested.

17. Document Analysis a. Descriptors

Bayes theorem	Accelerometers	Seismic waves
Attenuation	Reaction time	Mapping
		Earthquakes

b. Identifiers/Open-Ended Terms

Nicaragua

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
NTIS.		241
	20. Security Class (This Page)	22. Price A11-A01

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

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ACKNOWLEDGMENTS

The authors of this report wish to express their gratitude to Professor J. R. Benjamin, Professor J. M. Gere and Professor T. C. Zsutty for their comments and criticisms. Many hours of discussions held with Dr. Anne Kiremidjian were helpful in developing the Bayesian risk model.

The partial support provided by the Contrôle Technique de la Construction of Algeria and the John A. Blume Earthquake Engineering Center is gratefully acknowledged.

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CHAPTER I

INTRODUCTION

1.1 Introduction

The energy released by earthquakes propogates in the earth's crust as body and surface waves. The intensity and duration of shaking of structures located in the path of these waves depends upon the intensity and duration of the seismic ground motion along with the characteristics of the structure. Structural failures resulting in considerable damage and loss frequently occur because of these motions and inadequate seismic resistance of the structures.

Earthquake engineers and planners often use the words risk and hazard interchangeably in their work. Seismic risk is regarded by many to be synonymous with seismic hazard. There is some danger in this ambiguity since these two words for seismic phenomenon have different meanings. Seismic hazard is defined as "expected occurrence of future adverse seismic event (earthquake)". Seismic risk is defined as "expected consequences of future seismic event". Consequences may be life loss, economic loss, function loss and damage. Loosely, it can be said that a seismic hazard involves "nature's punch" while a seismic risk involves interaction between "nature's punch" and human activity.

The intensity and duration of future earthquake ground motions are random and can therefore be known only in the probabilistic sense of the likelihood of exceeding a given level during a given time period. (Rosenblueth and Esteva, 1966; Benjamin, 1968; Cornell, 1968*). If economic planning and engineering design criteria are to be formulated

* References are given at the end of the report.

on a rational basis, then it is necessary to have the best available estimates of these future ground motions. The best practical representation of earthquake loadings for a given geographical region is in the form of seismic hazard maps -- where the earthquake effect is shown in terms of the most useful engineering parameters for design. Presently there is a great need for improvements in risk mapping techniques and in the description of the related engineering parameters.

Therefore the present dissertation is divided in two parts. The first part concentrates on seismic hazard mapping which can be best defined as the exposure to seismic loading at a given location. This exposure is expressed in terms of an effect and the probability of its occurrence. The second part concentrates on a study of stable design parameters. Its general purpose is to provide a statistical and probabilistic view of the response of structures to earthquake excitation. The attention is focused on response parameters which have a direct engineering value.

Many attempts have been made to quantitatively describe the intensity or the severity of an earthquake (St. Amand, 1961; Howell, 1970; Blume, 1970, 1971; Trifunac and Brady, 1975). The intensity is usually expressed in terms of

- the amount of energy released at the hypocenter
- the effect on structures
- some design related parameters.

The widely used Richter magnitude (M) scale for rating the magnitude of an earthquake was proposed by Richter (1935) . This development initiated the rating of earthquakes according to their magnitude at the source independent of the ground shaking at other locations.

More recently the moment of an earthquake was proposed as a measure of the energy released (Aki, 1966). The modified Mercalli and Rossi-Forel intensity scales are based on the effect on structures of local ground shaking. Structural engineers have tried to quantify earthquakes in terms of parameters that are more closely related to the loads induced by a structural behavior such as peak value of the measured record of the earthquake (acceleration, velocity or displacement), frequency content and duration of the ground motion.

For several years hazard maps have been a common way to present expected seismic severity for a region. The level of sophistication of these maps varies greatly as illustrated by the following examples.

Consider the uniform building code (UBC) seismic zone map (1970), as shown in Fig. 1.1. Note that the title of the map indicates "Seismic Risk Map of the United States". This is a misnomer. This map indicates, to some scale, the future seismic hazard in different parts of the country. This map cannot and does not take into account any consequences due to a future seismic event. Also, as pointed out in the note appearing on the map, this map does not take into account the frequency of occurrence of earthquakes. Thus, for example, if one region had an intensity VIII event only once during the last 400 years, it is placed in Zone 3. At the same time, a region with ten intensity VIII or greater events in the last 100 years is also placed in Zone 3. In spite of such shortcomings, engineers use and depend on such maps in the designs. There is no attention paid to the amount of uncertainty in the loading and response of systems they design. It is very difficult to visualize perfect information with the use of such maps.

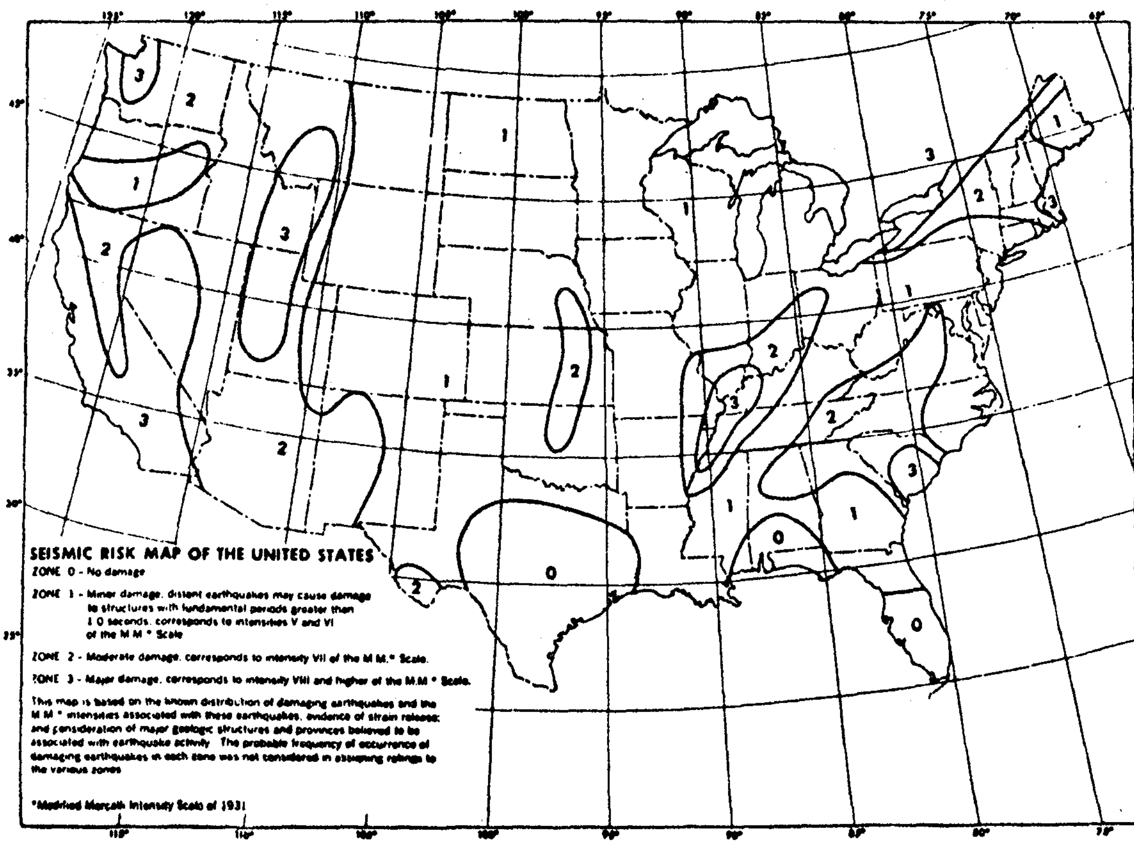

FIGURE 1.1. (UBC, 1970)

The evaluation of risk, using such maps, is not possible. Consider, for example, two locations in California, one near Sacramento and the other near Los Angeles. Also, consider that construction of similar facilities is planned at these two locations. Since the use and consequences of failure of these two facilities or structures located in two separate seismic regions is the same, the risk associated with the design should be similar. However, in using UBC zone maps, one would design both the facilities based on zone 3 factors. This means that either the facility near Los Angeles is underdesigned or the facility near Sacramento is overdesigned or both. For consistent seismic risk level for these two facilities, the site near Sacramento should have lower seismic design level compared to the site near Los Angeles. This brief argument points out the shortcomings of the current "risk maps".

Another recent development -- in the right direction -- is the work of Roger Greensfelder (1974) of the California Division of Mines and Geology. The revised August 1974 map of "Maximum Credible Rock Acceleration from Earthquakes in California" shows the peak rock acceleration levels in different parts of the state in the form of bedrock acceleration contours (Fig. 1.2). This is a hazard map. However, it has several major shortcomings. What is the return period for maximum credible rock acceleration? Is there a consistency in time? Are the frequencies the same for all levels for all regions? This information is very important for engineering design. Also, shall a designer use this map for warehouses, schools, hospitals? The map does not contain the information necessary for a consistent risk level based on use and consequences of failure of the structure. Thus, for a rational seismic

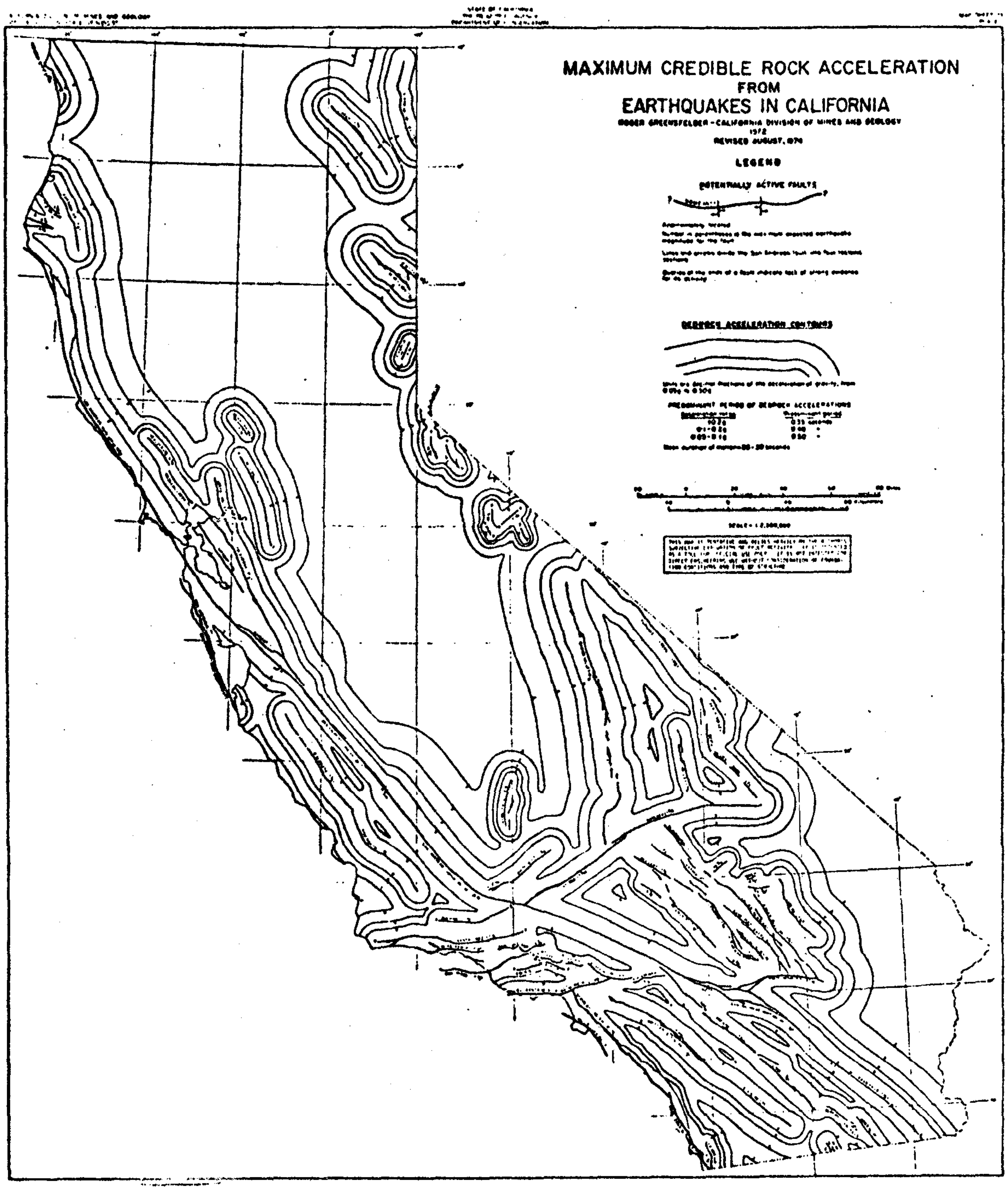

FIGURE 1.2. (Greensfelder, 1974)

risk analysis, a better methodology is needed.

Currently, there is considerable work done in the area of probabilistic estimation of seismic load parameters. In particular probabilistic forecasting in terms of iso-seismal and iso-acceleration maps has been studied. The usefulness of such maps is very much a function of the type and amount of information they contain. In order to best serve the needs of the structural engineering profession, any description of future earthquake ground motion should consist of information about the following:

1. Peak values (or other more descriptive parameters) of acceleration, velocity and displacement.
2. Frequency content.
3. Duration.

The following observations can be made:

- The peak values provide maximum amplitude but do not give any information about the other lower peaks contained in the record, whereas parameters such as mean and root mean square (RMS) values are based on the entire input record and therefore implicitly contain information about all the peaks and their distribution.
- The frequency content is generally represented by a response spectrum which provides the distribution of maximum response amplitudes at various frequencies (or periods).
- Duration is usually considered as the length of time over which "strong motion" is experienced.

None of the currently available procedures hazard mapping provide the complete information listed above. It is therefore the goal of the first part of this report to increase the amount of information contained in hazard maps.

1.2 Current Procedures

1.2.1 Peak Amplitudes

Current procedures for estimating seismic hazard in terms of peak amplitudes are summarized in Fig. 1.3. In essence, they consist of the following steps:

Step 1. Identification of Seismic Sources.

Based on the geology and historic seismicity of the region, sources are identified as line sources (faults) or area sources. The largest earthquake associated with each source is established from the historic seismicity and geology (in terms of magnitude or intensity). Typical examples of this approach are given in the following references: Cornell and Vanmarcke (1969), Algermissen (1969, 1975), Shah, et al., (1975), Wiggins (1975), Der Kiureghian and Ang (1975), Liu and Fagel (1975), Kiremidjian (1975).

Step 2. Recurrence of Earthquakes

The recurrence of earthquakes of various magnitudes is based primarily on the historic seismicity. A straight line or a set of straight lines is fitted on the data using regression analysis. This method usually results in prediction uncertainties of large magnitudes where the data is scarce. Some variations have been proposed to allow for the lack of data; Esteva (1969); Wiggins (1975) who uses a Bayesian procedure at the level of the results once the analysis is complete. Vagliente (1973) developed a seismic Markov model.

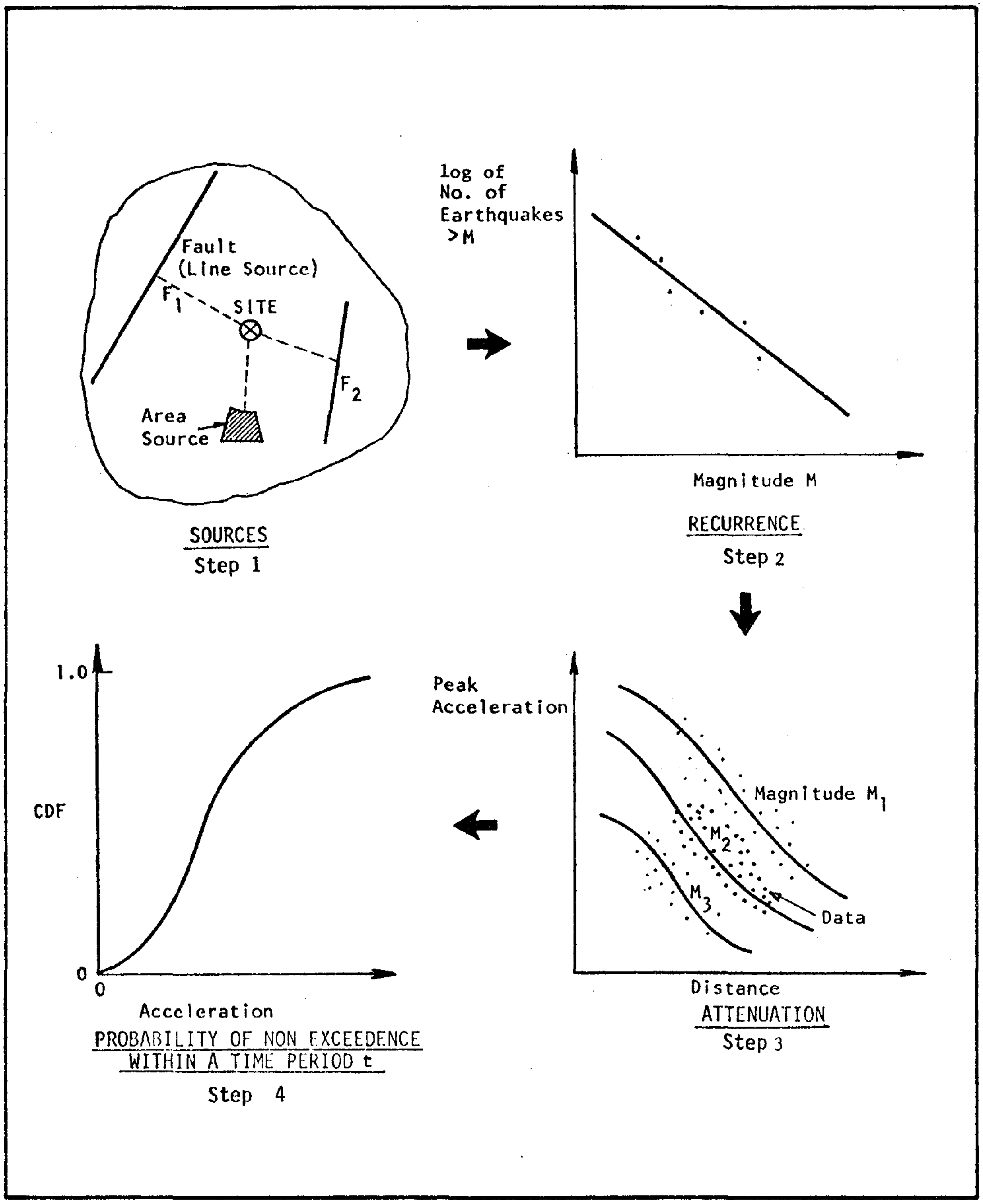

FIGURE 1.3. Current Approach to Hazard Mapping for Peak Values

Step 3. Selection of Attentuation Relationship

Using one of the numerous empirical attenuation relationships, the peak accelerations at a given site due to earthquakes of various sizes occurring at different source locations are estimated. The attenuation relationship is based on data of non-uniform quality since differences in recording techniques, local conditions, equipment reliability and human error are usually not taken into account. Most procedures utilize only the mean curves as determined from a regression analysis.

Step 4. Results

Utilizing the computations in Steps (1), (2) and (3) the probability that a certain acceleration will not be exceeded within a given time period t is determined. The results of the evaluation are presented in terms of iso-acceleration curves for selected levels of probabilities and time periods.

Fig. 1.4 shows a typical iso-acceleration map developed using the above procedure (Shah, et al., 1975). This map was developed for Nicaragua. The acceleration values of the iso-lines have a probability of 0.10 of being exceeded at least one time in fifty years. This is not a zoning map and values between the lines is obtained by interpolation. It should be pointed out that these maps by themselves do not help engineers in deciding the risk level they are taking or, for that matter, which map to use out of the many available for different time periods and different probabilities.

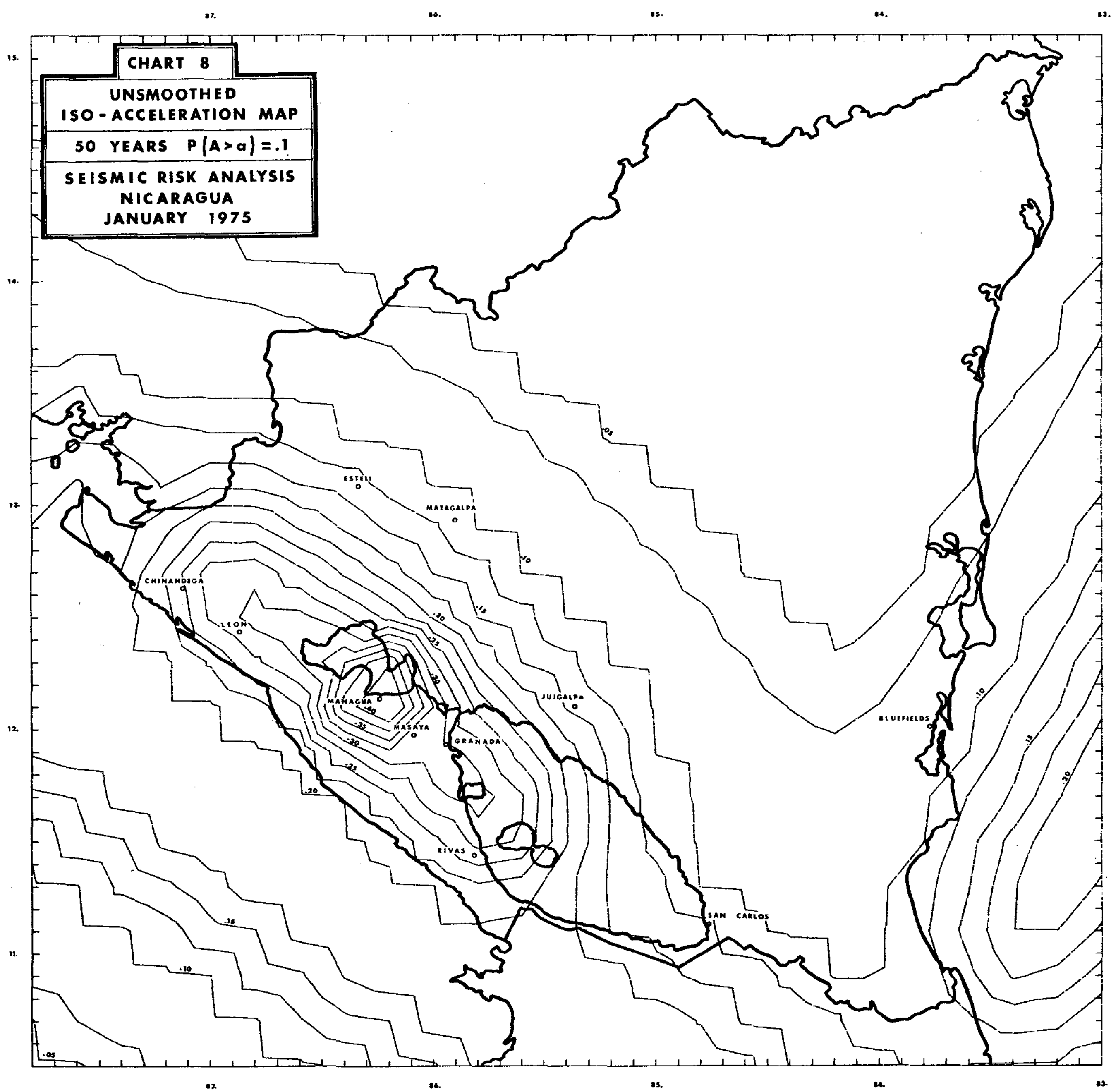

FIGURE 1.4. (Shah, et al. 1975)

1.2.2 Frequency Content

The two current approaches to mapping of frequency content are illustrated in Fig. 1.5 a and b respectively.

In the first approach, normalized response spectra are obtained for available accelerograms and a statistical analysis is made by either considering all spectra together (Clough, 1962; Blume, 1973) or by separating them by site conditions (Seed, et al., 1974). From the results (mean and coefficient of variation) of the statistical analysis response spectra for various probabilities of exceedence are established.

The second approach consists of the development of an attenuation (with distance) relationship for the peak response values for different periods or period bands. These attenuation relations are obtained by regression analysis on a number of response spectra. When combined with the recurrence relation at the sources, they can provide the probability distribution of peak responses for different periods or period bands at a given site (McGuire, 1975).

1.2.3 Duration

It is felt that this parameter is a most important measure of the damage producing capability of an earthquake and therefore it is to be incorporated in the maps developed herein. Some study of duration have been done (Trifunac and Brady, 1975; Dobry, et al., 1977) and some empirical relationships between magnitude, duration and distance have been obtained (Bolt, 1973). However, duration has never been included as a parameter in hazard map development.

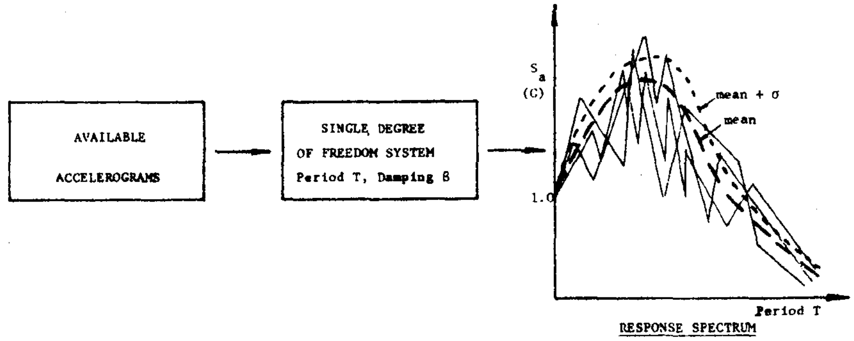

FIGURE 1.5(a). Statistics on Normalized Spectra

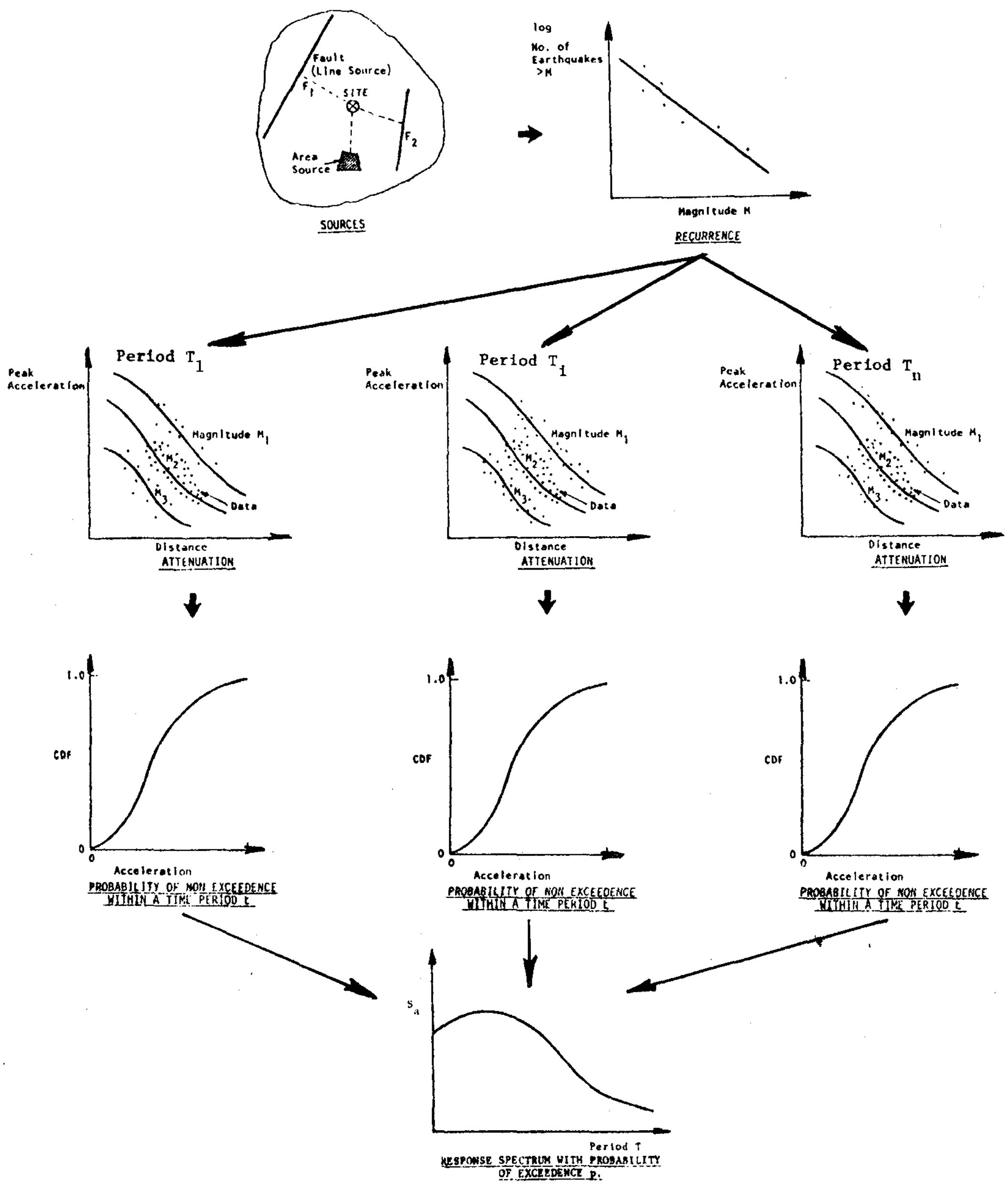

FIGURE 1.5(b). Attenuation of Spectral Values

FIGURE 1.5. Frequency Content
Current Procedures

1.3 Limitations

Limitations exist in the descriptive parameters and in the procedures presently used. These limitations are discussed as follows. Several possible improvements are presented in the next section.

1.3.1 Peak Amplitudes

While it is well known that peak amplitudes are useful parameters in the description of seismic loading, they are only partial indicators of earthquake motion. They are often the chance result of a random transient phenomenon and therefore do not show good correlation with the remaining general behavior of the motion. Moreover, they show considerable scatter even for earthquake events considered as similar (same distance from causative fault, same magnitude event and same soil site conditions).

Better and more stable parameters based on sufficient (mean and RMS) statistics rather than extreme values are needed to define the amplitude content of the ground motion. Such parameters or sets of parameters can be obtained by considering earthquake records in their entirety.

1.3.2 Recurrence Relationships

Recurrence equations based on regional historic seismicity data may be inaccurate for individual faults and specific areas. It has been observed that the short historical data base cannot represent the true state of nature. Figure 1.6 shows a typical case where the lack of data poses a critical problem for the analyst. Reliance on historical frequency data alone could result in erroneous conclusions. The simple extrapolation of the fitted curve beyond the range of the data, as it is

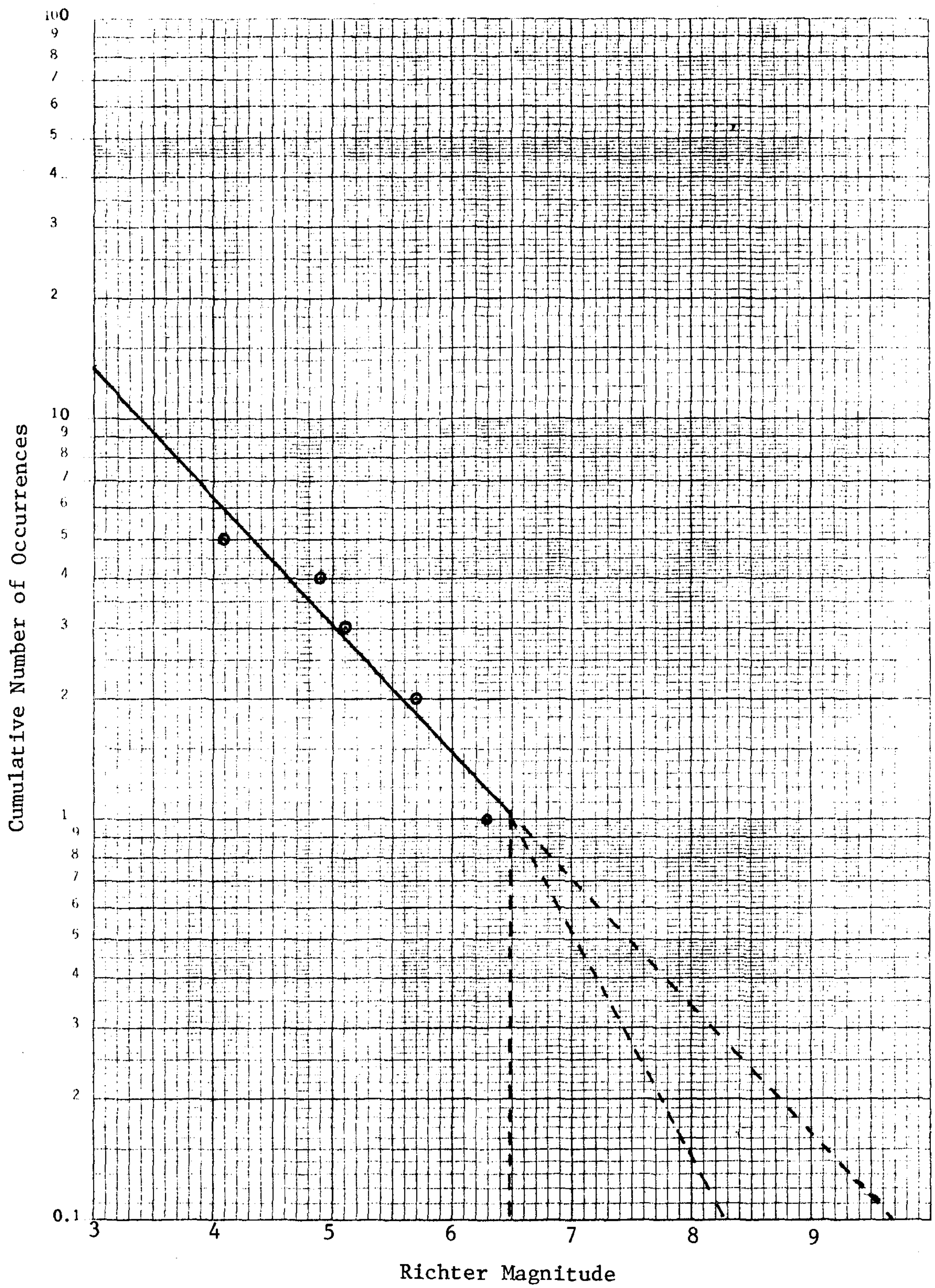

FIGURE 1.6. Typical Regression Graph

usually done in practice can be very dangerous since it is in this area that the magnitudes are governing any design decision.

The treatment of the data as discrete variables will help to solve this problem as presented in Chapter II. Inclusion of subjective geological and seismological opinion could increase the reliability and predictability of the source seismicity considerably. Bayesian statistics allowing combination of objective (or historical) data with subjective input in a rational and consistent way can greatly improve the accuracy of the predicted recurrence of a given magnitude.

1.3.3 Attenuation Relationships

Attenuation relationships for the variation of peak values with distance are significantly affected by the scatter of the peak values. Also a considerable amount of variation is due to non-uniform quality and amount of the basic data concerning past earthquakes. These conditions introduce large uncertainties in the prediction capabilities of the derived relation. While the probabilistic description of seismicity is well accepted and is best represented by hazard maps, it is often mentioned that the weakest link of the present description of seismicity resides in the uncertainties associated with the attenuation relationships. However, strangely enough, only the deterministic or mean value part of these relations is used and the possible random variation in the attenuation prediction is not considered at all. That is, a wide range of prediction uncertainty is completely ignored. This removes random uncertainty information where it is most needed and creates a break in the methodology. In order to be consistent with the probabilistic approach, a probabilistic treatment of attenuation is needed and can be achieved by considering the probability distribution of the predicted peaks for a given distance.

1.3.4 Response Spectra

Response spectra derived from statistical averaging of spectral shapes or regression analyses for data over all period ranges do not consider the probability of occurrence of each sample of data. They do not recognize each earthquake type (fault type, distance from site, etc.) with their corresponding probability of occurrence. Therefore some bias is likely to occur (one earthquake type versus another) and the spectral statistics developed will provide an accurate estimate of probability of exceedence only for specific period ranges and may be significantly in error for other periods.

1.3.5 Duration

Duration is possibly the single most important factor in producing excessive damage. (H. M. Engle in Richter, 1958). However, it is very seldom mentioned explicitly as a ground motion parameter. The reason being that it is not a design parameter per se and consequently no direct use of this information has been made as yet. Treatment and use of this parameter would add valuable information to hazard mapping.

1.4 Scope of Current Work

The present work focuses on the elimination of some of the limitations presented above. Special attention is to be given to:

- The Bayesian modeling of the seismic sources.

- The probabilistic treatment of attenuation relationship both for acceleration and duration.
- The replacement of peak values by more stable and representative design parameters.

1.4.1 Seismic Hazard Mapping

The steps of the general model used for seismic mapping in this study are presented below.

Source Location

The location of the sources is determined by using recorded hypocentral position of past earthquakes for the period over which historical records are available. Geological and seismological information is introduced to supplement the data and to present a coherent picture of the seismicity of the region. The spatial distribution of hypocenters is then divided in or assigned to different sources so as to model the earthquake generating process.

Seismic Model

In the data presently available, the most commonly used measure of earthquake magnitude is the Richter magnitude (M). In the current procedures, the seismicity of a source is described by the mean rate of occurrence of events greater than a given magnitude (recurrence relationship). In the present model, this seismicity is obtained in two steps. First the occurrences are considered independently of the magnitudes, then the probability distribution of the magnitudes is introduced as explained below:

- Occurrences: With the assumption that earthquake occurrences form a Poisson process with mean rate of occurrence independent of magnitude, a probability distribution is obtained on the number of occurrences for a given period of time for a given source. The assumption of spatial and temporal independence is fairly well verified by data and is a common accepted practice in seismology. Moreover the amount of dependence due to the dual mechanism of stress accumulation and release has not been determined as yet.
- Magnitudes: Given that an event has occurred, a probability distribution of the Richter magnitudes (M) is determined from past data. The M are discretized at every 1/4 unit as is commonly done in data recording. This representation has the advantage of getting away from the curve of line fitting. This method is specially valuable for regions where very little data is available. The probability corresponding to each magnitude can be used in a Bernoulli trial where one outcome will be an event of the magnitude considered (success) and the other an event of any other magnitude (failure). The following question can then be answered: "Given that n earthquakes will occur in future time t, what is the probability that there will be 0, 1, 2 ... n events of any given magnitudes?" Combining these binomial conditional distributions with the Poisson distribution of occurrences, the distribution of the number of occurrences of each magnitude can be obtained.

Bayesian Statistics

Bayesian statistics are applied to the Poisson and binomial laws to supplement some of the incompleteness of the data. For example, with consideration of the fault length and the type of fault, geologists can determine the maximum magnitude earthquake that the source can generate. This information has to be taken into account even if no such earthquake had been recorded in the data. This can be done by assuming the mean rate of occurrences of the Poisson law to be a gamma probability distribution and the probability of success of the binomial law to be a beta probability distribution. This method has the advantage of including personal experience together with the data as well as updating the distribution as new data are made available.

Mapping Parameters

Two mapping parameters are used, namely the peak ground acceleration (PGA) and the duration of the ground motion. PGA is used since no other attenuation relationship is readily available in the literature. The methodology allows for the use of a more stable parameter such as RMS which would certainly improve the reliability of the model. More will be said about RMS and stable parameters in later sections.

Attenuation Relationships

The Esteva (1974) relationship is used to relate the PGA to M and hypocentral distance. Attenuation of duration is obtained using the relation developed by Bolt (1973).

Both relationships are treated probabilistically to take into consideration uncertainties in the attenuation decay. A first order probabilistic representation in the form of mean and coefficient of variation is introduced in this work.

Probabilistic Estimation of PGA and Duration

Combining the distributions that describe the seismicity at the sources with the two attenuation functions (for acceleration and duration), the probability of exceedence of any PGA or duration is to be obtained at the site.

Case Study

A case study of seismic mapping for the country of Nicaragua is presented.

1.4.2 Study of Stable Design Parameters

In order to develop a proper understanding of recorded time histories a detailed statistical analysis of relevant parameters associated with these time histories is necessary. Such an in-depth study is presented with the following goals in mind:

- To develop a stable parameter (or parameters) which can describe the behavior of the seimic recorded input or of response output of linear single degree of freedom systems.
- To relate the developed stable parameters to "design" parameters currently used by engineers; e. g., peak ground acceleration and response spectra values.
- To incorporate seismic hazard map development with the utilization of stable parameters and currently used design procedures.

With these goals in mind, a set of 97 earthquake time histories are studied. It should be pointed out that in order to study an earthquake time history in its entirety, one should investigate the statistical properties in the time domain and the frequency domain. The time domain analysis involves the study of the recorded motion in terms of the duration and other amplitude related statistical parameters. The most widely used frequency analysis involves the study of response time histories of linear one degree of freedom system (for a given damping and period) to the given earthquake record.

The current study investigates the following parameters of each of the 97 records considered.

(A) Input parameters obtained from recorded accelerograms

- Duration
- Mean acceleration
- Root mean square (RMS) of acceleration
- Probability distribution of peaks
- Parameter a_p defined as the acceleration which has probability p of being exceeded for a given record.
- The ratio $K_1 = a_p/RMS$

(B) Response parameters obtained from acceleration response history of a linear single degree of freedom system with damping ratios 5%, 10% and 20% and natural period range of .08 sec. to 5.0 sec.

- Duration
- Mean acceleration
- Peak response (corresponds to spectral value)

- RMS of acceleration

- Probability distribution of response peaks

- Parameter a_p defined as the response acceleration which has probability p of being exceeded for the given response.

- The ratio $K_1 = a_p/RMS$

- Cumulative potential energy per unit mass (ENGY) in response time history. (This will be further described in Chapter IV.)

- The ratio $K_2 = RMS^2 \cdot T^2/(ENGY/NBPK)$ in the above ratio, T is the period of the structure and NBPK is the number of peaks of the response time history.

In Chapter V and VI the stable behavior of the ratios K_1 and K_2 and their relevancy are described and discussed.

Development of an entirely new and fresh approach in earthquake engineering has its drawbacks. First, the practical implication of a new method of seismic hazard mapping for peak acceleration and duration cannot be assessed at this time. Second, the use and implication of new stable parameters describing the ground motion and the response together with the currently used parameters can only be achieved with time. At times, the reader of this work will feel that a "total story" involving the hazard mapping, the use of stable parameters and design procedure is not presented. It is not the intent of this report to present such a "story". It is hoped that the ideas developed in this work will be further studied and incorporated into a design methodology by future researchers and practicing engineers.

CHAPTER II

METHODOLOGY FOR SEISMIC HAZARD MAPPING

2.1 Introduction

This chapter concentrates on seismic hazard mapping which can be defined as the exposure to seismic loading at a given location. This exposure is expressed in terms of the severity of an effect and the probability of its occurrence.

The seismic hazard mapping model is divided in the following steps:

- Identification of Earthquake Sources

  The locations of the sources are determined by using recorded hypocentral position of past earthquakes together with geological and seismological information.

- Development of an Earthquake Recurrence Model

  The seismicity of a source is obtained in two steps. First the occurrence of events is considered independently of the magnitudes, then the probability distribution of the magnitudes is introduced.

- Choice of Seismic Ground Motion Parameters

  Different mapping parameters are presented and discussed. Peak ground acceleration (PGA) and duration are chosen for this work together with corresponding attenuation relationships.

- Probabilistic Estimation of PGA and Duration

  The probability of exceedence of any PGA and duration is obtained at the site considered by combining the probability distributions that describe the seismicity of the sources with the two attenuation functions.

Because of the limitations inherent in the current procedures of hazard mapping,special attention is given to:

- The Bayesian modeling of the earthquake recurrence phenomenon
- The use of two mapping parameters: peak acceleration and duration
- The probabilistic treatment of attenuation relationships

2.2 Identification of Seismic Sources

The locations of the sources are identified using the recorded hypocentral position of past earthquakes together with geological and seismological information. The spatial distribution of hypocenters is then divided in different sources as a function of their shape and seismicity. Two types of sources can be used to represent the seismicity of any region. They are the line and area sources.

Most of the earthquake epicenters around the world are located around major fault systems. Thus, the usual case of epicenters falling along a line gives rise to the so-called "line source". A number of straight lines may be necessary to model a fault to satisfy geometric considerations (curve shaped faults) or seismic considerations (variation in seismicity along a fault). The seismicity is assumed to be homogeneous over a segment.

In many parts of the world there are regions where the epicenters are not located along a line but are scattered all over a region (Gutenberg and Richter, 1954). This may be due to the existence of numerous faults criss-crossing the region or due to errors in estimation of epicentral locations. Thus, there are places where line sources may not fit the scatter of epicentral locations. For such cases, area sources are used to determine probabilistic loading at the site. In the present model the area can either be a circle or a rectangle. The seismicity is assumed to be homogeneous over the area source.

2.3 Development of an Earthquake Recurrence Model (A Bayesian Approach)

2.3.1 Introduction

It has been observed that short or partial historical data bases cannot represent the true state of nature. Reliance on frequency data alone can result in erroneous conclusions. Inclusion of geological and seismological opinions can increase considerably the reliability and predictability of the seismicity. For this reason a Bayesian approach is adopted and used in this work.

In the data presently available, the most commonly used numerical measure of earthquake severity is the Richter magnitude. In this model, the magnitudes are discretized to every 1/4 unit of Richter magnitude (M_i) as it is commonly done in data recording. The seismicity of the sources is described by the distribution of the number of occurrences of each magnitude. This representation permits the use of discrete models and has the advantage of getting away from data fitting which usually results in unacceptable uncertainties for large magnitudes where the data is scarce. Moreover, it leads to a direct and elegant use of Bayesian statistics.

The development is done in three steps:

- Assuming that earthquake occurrences form a Poisson process with mean rate of occurrence independent of magnitude, a distribution is obtained on the number of occurrences for the time period considered.

- Given that an event has occurred, a distribution on the magnitude of events is determined from past data. The process generating model can be assumed to be Bernoulli. The probability of success p_{M_i} corresponding to each trial is defined as the probability that the event that has occurred is of magnitude M_i. Thus the probability of failure $q_{M_i} = 1 - p_{M_i}$, at each trial is the probability that the event is not of magnitude M_i. The probability of having r events of magnitude M_i given that a total of n events have occurred can therefore be obtained using the binomial distribution.
- The distribution of the number of events of each magnitude independently of the number of trials is obtained by combining step one and two.

2.3.2 Occurrences

2.3.2.1 Poisson Model

Once the seismic sources have been located, it is assumed that earthquake occurrenceson each source form a Poisson process with mean rate of occurrence independent of magnitudes. For earthquake events to follow the Poisson model, the following assumptions must be valid:

(1) Earthquakes are spatially independent

(2) Earthquakes are temporally independent

(3) Probability that two seismic events will take place at the same time and at the same location approaches zero.

The first assumption implies that occurrence or non-occurrence of a seismic event at one site does not affect the occurrence or non-occurrence of another seismic event at some other site. The second assumption implies that the seismic events do not have memory in time. The assumptions of spatial and temporal independence have been fairly well verified by data and are commonly accepted practices. The degree of dependence due to the dual mechanism of stress accumulation and release has not been determined with any amount of precision as yet and seems to fade away quite rapidly with time (Gardner and Knopolf, 1974). The third assumption implies that for a small time interval, Δt, more than one seismic event cannot occur on one source. This is a very realistic and good assumption which fits the physical phenomenon.

Hence, considering all the events of magnitude greater than an arbitrary lower bound, a distribution is obtained on the number of occurrences for a given period of time t. The lower bound is chosen such that earthquakes of magnitude smaller than the one specified have a negligible damage potential and can thus be disregarded. This is done for each seismic source.

In its most general form, the conditional Poisson law can be written as

$$p_N(n/\lambda) = \frac{e^{-\lambda t}(\lambda t)^n}{n!}, \qquad t > 0; \quad n \text{ integer} \geq 0 \qquad (2.1)$$

where $p_N(n/\lambda)$ = Probability of having n events in time period t, given λ.

n = Number of events.

λ = Mean rate of occurrence per unit of time.

$\mu_N = \lambda$

$\sigma_N^2 = \lambda$

2.3.2.2 Bayesian Probability

A Bayesian approach is used so that historical data and subjective information can be effectively combined and used in the analysis. If one assumes that the number of seismic events for a future time t follows a Poisson probability law, there is still uncertainty about the parameter λ, the mean rate of occurrence (Eq. 2.1). Therefore. λ is treated as a random variable. The probabilistic information on λ can be obtained through historical data or from the subjective knowledge of the analyst. The subjective probability distribution on λ is called the prior distribution. Using the historical information, one can obtain the sample likelihood function on λ. Combining the prior distribution and the sample likelihood function by means of Bayes' theorem, the posterior distribution on λ can be obtained (Benjamin and Cornell, 1970).

Let $f'_\Lambda(\lambda)$ be the prior probability distribution function on λ.

Let $L(\lambda)$ be the sample likelihood function on λ.

Then using Bayes' theorem the posterior distribution $f''_\Lambda(\lambda)$ is obtained as:

$$f''_\Lambda(\lambda) = N_1 L(\lambda) f'_\Lambda(\lambda) \tag{2.2}$$

where N_1 is a normalizing constant.

In the following sections, the concept of conjugate prior is used for analytical simplicity.

Prior Distribution on λ

For convenience the prior distribution for the random variable λ is chosen as the gamma distribution with parameters λ' and ν'. Since the gamma distribution can fit a large variety of shapes this choice does not introduce any limitations in the model (Raiffa and Schlaifer, 1961). The parameters λ' and ν' are obtained directly from the subjective input and the prior can thus be written:

$$f'_\Lambda(\lambda) = \frac{\lambda'(\lambda'\lambda)^{\nu'-1}e^{-\lambda'\lambda}}{\Gamma(\nu')} \quad \lambda \geq 0;\ \lambda' > 0;\ \nu' > 0 \tag{2.3}$$

where $\Gamma(\nu') = \int_0^\infty e^{-u}u^{\nu'-1}du$

$$\mu_\Lambda = \frac{\nu'}{\lambda'}$$

$$\sigma_\Lambda^2 = \frac{\nu'}{\lambda'^2}$$

Sample Likelihood Function

For any given source, the available data indicates that in the past T years, N earthquakes of Richter magnitude greater than the lower bound have occurred. This information is used in the construction of the sample likelihood function. Since the event-generating process is assumed to be a Poisson process, the sample likelihood function on λ is given by

$$L(\lambda/N,T) = \frac{e^{-\lambda T}(\lambda T)^N}{N!} \quad T > 0;\ N \geq 0 \tag{2.4}$$

where T = Time of the data base

N = Number of events greater than a fixed lower bound M observed during time period T.

Posterior Distribution on λ

Using equations 2.2 and 2.3 the posterior distribution on λ can be written as

$$f''_\Lambda(\lambda) = N_1 \cdot \frac{e^{-\lambda T}(\lambda T)^N}{N!} \cdot \frac{\lambda'(\lambda'\lambda)^{\nu'-1} e^{-\lambda'\lambda}}{\Gamma(\nu')} \tag{2.5}$$

The value of the normalizing constant N_1 can be evaluated by noting that $f''_\Lambda(\lambda)$ is a probability distribution function. Thus,

$$\int_0^\infty f''_\Lambda(\lambda) d\lambda = 1.0 \tag{2.6}$$

Rearranging and substituting the values of N_1 in equation 2.5

$$f''_\Lambda(\lambda) = \frac{\lambda''(\lambda''\lambda)^{\nu''-1} e^{-\lambda''\lambda}}{\Gamma(\nu'')}, \qquad \lambda \geq 0; \ \lambda'' > 0; \ \nu'' > 0 \tag{2.7}$$

where $\lambda'' = \lambda' + T$

$\nu'' = \nu' + N$

$\mu_\Lambda = \dfrac{\nu''}{\lambda''}$

$\sigma^2_\Lambda = \dfrac{\nu''}{\lambda''^2}$

Note that the posterior distribution of λ is also gamma type.

In equation 2.1, the conditional probability on the number of events n is based on λ. The unconditional or the marginal distribution on n can be obtained by using equation 2.7 together with equation 2.1 and integrating over all λ's. Thus

$$\begin{aligned} p_N(n) &= \int_0^\infty p_N(n,\lambda) d\lambda \\ &= \int_0^\infty p_N(n/\lambda) f''_\Lambda(\lambda) d\lambda \\ &= \int_0^\infty \frac{e^{-\lambda t}(\lambda t)^n}{n!} \frac{\lambda''(\lambda''\lambda)^{\nu''-1} e^{-\lambda''\lambda}}{\Gamma(\nu'')} d\lambda \qquad (2.8) \end{aligned}$$

-continued-

$$= \int_0^{\infty} \frac{e^{-\lambda(t + \lambda'')} t^n \lambda''^{\nu''} \lambda^{n+\nu''-1}}{n!\Gamma(\nu'')} d\lambda \tag{2.8}$$

-continued-

which leads to

$$p_N(n) = \frac{\Gamma(n + \nu'')}{n!\Gamma(\nu'')} \cdot \frac{t^n \lambda''^{\nu''}}{(t + \lambda'')^{n+\nu''}} \tag{2.9}$$

for n integer ≥ 0

$\nu'' > 0$

$\lambda'' > 0$

$t > 0$

When ν'' has integer values, equation 2.9 can be rewritten

$$p_N(n) = \frac{(n + \nu'' - 1)!}{n!(\nu'' - 1)!} \frac{t^n \lambda''^{\nu''}}{(t + \lambda'')^{n+\nu''}} \tag{2.10}$$

for n integer > 0

ν'' integer > 0

$\lambda'' > 0$

$t > 0$

Equation 2.9 and 2.10 are called the marginal Bayesian distributions of n. These distributions, after taking into consideration the uncertainties on the mean rate of occurrence, give the probability of the number of events above a predetermined lower bound M, in time period t.

2.3.2.3 Weight of the Prior Distribution

The subjective information of the expert is expressed in the form of a prior distribution on λ. It is assumed that a gamma distribution will fit the prior and the parameters λ' and ν' are obtained directly from the shape of this distribution. The physical meaning of λ' and ν' can be explained as follows: λ' can be interpreted as the equivalent time period over which the analyst bases his subjective input whereas ν' can be interpreted as the equivalent number of occurrences during this time period. Hence if $\lambda' = T$, both the prior and the data will have the same weight. If $\lambda' \gg T$, the weight of the prior overshadows the importance of the data. It implies that the expert has more confidence in his personal feeling than in the data. A complete analysis of the weight of the prior is given in Raiffa and Schlaifer (1961).

2.3.3 Richter Magnitude

2.3.3.1 Introduction

Up to this point, the seismicity of a source has been defined only by the distribution on the number of events that this source may generate in a given time period t. The next step consists in the representation of information on the severity of these events. Several parameters are suitable for this purpose such as energy release, intensity and Richter magnitude. The Richter magnitude is the parameter chosen herein since most of the available data is recorded in terms of this quantity. The Richter magnitudes are discretized every 1/4 Richter unit (M_i) as commonly done in seismology. The number of different M_i's expected to occur is thus finite. This allows for the use of a discrete model.

2.3.3.2 Bernoulli Model

A Bernoulli trial is used to model information on magnitudes. Given that an event has occurred, the probability that it is of any given Richter magnitude can be represented in terms of a Bernoulli trial. If the seismic event that has occurred is of the M under consideration, then the outcome of the Bernoulli trial is a success. Conversely, failure at each trial implies that the seismic event that has occurred is of M other than the one under consideration.

If p_{M_i} = probability of success at each trial corresponding to M_i.

and

$$q_{M_i} = 1 - p_{M_i}$$

$$= \text{probability of failure at each trial,}$$

then using the binomial law,

$$p_R(r_{M_i}/n, p_{M_i}) = C_n^{r_{M_i}} \, p_{M_i}^{r_{M_i}} (1 - p_{M_i})^{n - r_{M_i}} \tag{2.11}$$

for n integer > 0

r_{M_i} integer; $0 \leq r_{M_i} \leq n$

$0 \leq p_{M_i} \leq 1$

where $p_R(r_{M_i}/n, p_{M_i})$ is read as the probability that r_{M_i} events M_i will occur out of a total of n events given that the probability of occurrence of M_i is p_{M_i} at each trial,

and $$C_n^{r_{M_i}} = \frac{n!}{r_{M_i}!(n - r_{M_i})!}$$

A different probability p_{M_i} is obtained for each M_i considered in the model. A relation similar to equation 2.11 is thus obtained for each of the Richter magnitudes. It is important to recognize that the probabilities p_{M_i} are mutually exclusive for the different magnitudes hence

$$\sum_{\text{all } M_i} p_{M_i} = 1.0 \quad . \tag{2.12}$$

2.3.3.3 Bayesian Probability.

Equation 2.11 represents the generating process for the number of events M_i. However, this information is conditional on the knowledge about p_{M_i}, the probability of success corresponding to M_i. To rationally incorporate the historical as well as subjective information on p_{M_i}, this parameter is treated as a random variable and a Bayesian formulation is used.

Prior Distribution on p_{M_i}

The conjugate prior distribution on p_{M_i} is assumed to be beta type. Since the normalized beta distribution is bounded between 0 and 1 and fits a large variety of shapes, this choice does not introduce any limitations in the model (Raiffa and Schlaifer, 1961). The beta form of this prior is thus given by:

$$f'_P(p_{M_i}) = \frac{1}{B'_{M_i}} p_{M_i}^{\xi'_{M_i}-1} (1 - p_{M_i})^{\eta'_{M_i} - \xi'_{M_i} - 1} \tag{2.13}$$

for $0 \leq p_{M_i} \leq 1$

$\xi'_{M_i} \geq 0$

$\eta'_{M_i} - \xi'_{M_i} \geq 0$

where
$$B'_{M_i} = \frac{\Gamma(\xi'_{M_i})\Gamma(\eta'_{M_i} - \xi'_{M_i})}{\Gamma(\eta'_{M_i})}$$

$$\mu_{P_{M_i}} = \frac{\xi'_{M_i}}{\eta'_{M_i}}$$

$$\sigma^2_{P_{M_i}} = \frac{(\xi'_{M_i})(\eta'_{M_i} - \xi'_{M_i})}{\eta'_{M_i}(\eta'_{M_i} + 1)}$$

where the parameters η'_{M_i} and ξ'_{M_i} are obtained from the subjective information.

A prior distribution of a similar form has to be assumed for each of the magnitudes considered. Here again, the prior distribution are not independent and the following condition must be satisfied:

$$\sum_{\text{all } M_i} \frac{\xi'_{M_i}}{\eta'_{M_i}} = 1.0 \tag{2.14}$$

<u>Sample Likelihood</u>

The usual form of the available data indicates that among the N earthquakes observed on a given source, R_{M_i} were M_i. This information is used in the construction of the sample likelihood function. Noting that the generating process (eq. 2.11) is a binomial process, the sample likelihood function on p_{M_i} is given by

$$L(p_{M_i}/N, R_{M_i}) = p_{M_i}^{R_{M_i}}(1 - p_{M_i})^{N-R_{M_i}} . \tag{2.15}$$

This operation must be repeated for each of the different magnitudes considered. Each of these sample likelihood functions must be combined with the corresponding prior distributions to obtain the posterior distributions.

Posterior Distribution on p_{M_i}

As described in Section 2.3.2.2, the posterior distribution on p_{M_i} is obtained from equations 2.13 and 2.15 and can be written as

$$f''_P\,(p_{M_i}) = N_1\left[\, p_{M_i}^{R_{M_i}}(1-p_{M_i})^{N-R_{M_i}}\right]\cdot\left[\frac{1}{B'_{M_i}}p_{M_i}^{\xi'_{M_i}-1}\,(1-p_{M_i})^{\eta'_{M_i}-\xi'_{M_i}-1}\right] \tag{2.16}$$

Applying the condition

$$\int_0^1 f''_P\,(p_{M_i})dp_{M_i} = 1.0 \tag{2.17}$$

one obtains

$$f''_P(p_{M_i}) = \frac{1}{B''_{M_i}}\cdot p_{M_i}^{\xi''_{M_i}-1}\cdot(1-p_{M_i})^{\eta''_{M_i}-\xi''_{M_i}-1} \tag{2.18}$$

for $0 \le p_{M_i} \le 1$

$\xi''_{M_i} \ge 0$

$\eta''_{M_i} - \xi''_{M_i} \ge 0$

where $\xi''_{M_i} = \xi'_{M_i} + R_{M_i}$

$\eta''_{M_i} = \eta'_{M_i} + N$

$$B''_{M_i} = \frac{\Gamma(\xi''_{M_i})\Gamma(\eta''_{M_i} - \xi''_{M_i})}{\Gamma(\eta''_{M_i})}$$

Note that the posterior distribution on p_{M_i} is also beta type.

In equation 2.11, the conditional probability on the number of successes r_{M_i} is based on p_{M_i} and n. The condition on p_{M_i} can be removed using equation 2.18 and integrating over all the values of p_{M_i} as follows:

$$p_R(r_{M_i}/n) = \int_0^1 p_R(r_{M_i}, p_{M_i}/n)\,dp_{M_i}$$

$$= \int_0^1 p_R(r_{M_i}/p_{M_i}, n) f_P''(p_{M_i})\,dp_{M_i}$$

$$= \int_0^1 C_n^{r_{M_i}} p_{M_i}^{r_{M_i}} (1-p_{M_i})^{n-r_{M_i}} \frac{1}{B''_{M_i}} p_{M_i}^{\xi''_{M_i}-1} (1-p_{M_i})^{\eta''_{M_i}-\xi''_{M_i}-1}\,dp_{M_i}$$

$$= C_n^{r_{M_i}} \frac{1}{B''_{M_i}} \int_0^1 p_{M_i}^{r_{M_i}+\xi''_{M_i}-1} (1-p_{M_i})^{n+\eta''_{M_i}-(r_{M_i}+\xi''_{M_i})-1}\,dp_{M_i} \quad (2.19)$$

setting $r_{M_i} + \xi''_{M_i} = \alpha_{M_i}$

$n + \eta''_{M_i} = \beta_{M_i}$

one can write

$$p_R(r_{M_i}/n) = C_n^{r_{M_i}} \left[\frac{\Gamma(\eta''_{M_i})}{\Gamma(\xi''_{M_i})\Gamma(\eta''_{M_i}-\xi''_{M_i})} \cdot \frac{\Gamma(\alpha_{M_i})\Gamma(\beta_{M_i}-\alpha_{M_i})}{\Gamma(\beta_{M_i})} \right] \quad (2.20)$$

for n integer > 0

r_{M_i} integer

$0 \leq r_{M_i} \leq n$.

The above expression is the distribution on the number of earthquakes of a fixed M_i given that n earthquakes have occurred. There is a similar distribution for each M_i considered.

2.3.3.4 Weight of the Prior Distribution

The parameters η'_{M_i} and ξ'_{M_i} are obtained directly from the shape of the prior distribution assumed to be of the beta type. The physical meaning of these parameters can be explained as follows: η'_{M_i} can be interpreted as the equivalent number of trials on which the expert bases his subjective input and ξ'_{M_i} as the equivalent number of successes. Hence if $\eta'_{M_i} = N$, both the prior and the data have the same weight. If $\eta'_{M_i} \ll N$, the weight of the data overshadows the importance of the prior. This implies that the expert has more confidence in the data than in his personal feelings.

2.3.4 Marginal Distribution on the Number of Magnitudes

In order to obtain the probability on the number of earthquakes of fixed magnitude regardless of the total number of occurrences, one removes the condition on the number of events n in equation 2.20 by taking the summation over all the events. The distribution on the number of events is given by equation 2.9. Hence

$$p_R(r_{M_i}) = \sum_{n=0}^{\infty} p_R(r_{M_i}/n)p_N(n)$$

$$\sum_{n=0}^{\infty}\left[C_n^{r_{M_i}} \frac{\Gamma(\eta''_{M_i})}{\Gamma(\xi''_{M_i})\Gamma(\eta''_{M_i}-\xi''_{M_i})} \cdot \frac{\Gamma(r_{M_i}+\xi''_{M_i})\Gamma(n+\eta''_{M_i}-r_{M_i}-\xi''_{M_i})}{\Gamma(n+\eta''_{M_i})} \cdot \frac{\Gamma(n+\nu'')t^n\lambda''^{\nu''}}{n!\Gamma(\nu'')(t+\lambda'')^{n+\nu''}}\right] \tag{2.21}$$

In the particular case where $r_{M_i} = 0$, the above expression becomes:

$$P(r_{M_i} = 0) = \sum_{n=0}^{\infty} \left[\frac{\Gamma(\eta''_{M_i})}{\Gamma(\xi''_{M_i})\Gamma(\eta''_{M_i} - \xi''_{M_i})} \cdot \frac{\Gamma(\xi''_{M_i})\Gamma(n+\eta''_{M_i} - \xi''_{M_i})}{\Gamma(n + \eta''_{M_i})} \cdot \frac{\Gamma(n+\nu'')t^n \lambda''^{\nu}}{n!\Gamma(\nu'')(t+\lambda'')^{n+\nu}} \right] \tag{2.22}$$

In the particular case where ν'', $\eta''_{M_i}, \xi''_{M_i}$ are integer values, the gamma functions can be expressed as factorials and the two above expressions become

$$p_R(r_{M_i}) = \sum_{n=0}^{\infty} \left[\frac{1}{r_{M_i}!(n-r)!} \frac{(\eta''_{M_i} - 1)!}{(\xi''_{M_i}-1)(\eta''_{M_i} - \xi''_{M_i} - 1)!} \frac{(r_{M_i}+\xi''-1)!(n+\eta''_{M_i} - r_{M_i} - \xi''_{M_i} - 1)!}{(n - \eta''_{M_i} - 1)!} \cdot \frac{(n - \nu'' - 1)!}{(\nu'' - 1)!} \frac{t^n \lambda''^{\nu''}}{(t+\lambda'')^{n+\nu''}} \right] \tag{2.23}$$

$$P(r_{M_i} = 0) = \sum_{n=0}^{\infty} \left[\frac{1}{n!} \cdot \frac{(\eta''_{M_i} - 1)!}{\xi''_{M_i}-1)!(\eta''_{M_i} - \xi''_{M_i} - 1)!} \frac{(\xi''_{M_i}-1)!(n-\eta''_{M_i}-\xi''_{M_i}-1)!}{(n + \eta''_{M_i} - 1)!} \frac{(n - \nu'' - 1)!}{(\nu'' - 1)!} \cdot \frac{t^n \lambda''^{\nu''}}{(t + \lambda'')^{n+\nu''}} \right] \tag{2.24}$$

These distributions describe totally the seismicity of the source considered in terms of the two parameters: magnitudes (M_i) and number of occurrences (n).

In most cases however, the objective involves the description of seismicity at a given site rather than of a source or a number of sources. The method commonly applied consists of the use of transfer functions to determine the effect of the combined sources on the site. The principle of this method has been described extensively in the literature (Dalal, 1973; Shah, et al., 1975) and will not be presented in this stucy although it will be used with some modifications.

2.4 Choice of Seismic Ground Motion Parameters

2.4.1 Introduction

Seismic loadings at a given site cannot be directly related to earthquake magnitude measures, such as M, energy release, etc. At a given distance from the epicenter these loadings are dependent upon the ground motion characteristics and the structural characteristics. The ground motion characteristics can be broadly described by intensity, amplitude of motion, frequency content and duration (Gutenberg and Richter, 1956). The intensity is an overall measure of the severity of the ground shaking which may be used to normalize different ground motions for purposes of comparison. The recorded peak value of the acceleration, velocity or displacement is often used to describe the amplitude of ground motion. Other measures of amplitude such as RMS or percentile of exceedence are presented in Chapter IV of this dissertation. Frequency content is a measure of the relative predominance of various frequencies present in the motion. Duration is the length of time for which the significant ground motion lasts.

Since both intensity and frequency content are indicators of the ground motion severity, frequency content related intensity measures have been proposed (Housner).

The frequency content related intensity measures are more meaningful in the representation of the ground motion severity than the ground motion parameters, such as peak acceleration, velocities or displacements. However, the later are more widely used. They are selected as indicators of the ground motion intensity because of the simplicity and convenience in their determinations and use. The peak ground acceleration is more widely used than the peak velocity and displacement.

The duration of motion is a parameter not often explicitly taken into consideration either in the intensity determination or in the specification of design criteria. Its importance has however been recognized (Richter, 1958; Bolt, 1973; Trifunac, 1976; Dolbry, et al., 1977).

Peak ground acceleration together with the duration of motion are adopted in this work as the intensity measure of the motion at a site. Various other parameters will be described in Chapter IV of this report. The peak ground acceleration parameter is adopted herein mainly to check as to how the present model compares with others using this parameter. In Chapter III results will be compared with the ones presented in Shah, et al., (1975).

2.4.2 Relation between Richter Magnitude and Ground Acceleration

Several empirical relationships between peak ground motion parameters and M have been proposed and employed in practice. All of these relationships have been derived by regression-type statistical analysis of the pertinent ground motion data.

Housner (1969) has proposed a procedure to determine peak ground accelerations incorporating magnitude, fault length, felt area and hypothetical elliptic shapes of felt areas. Wiggins (1964) has derived a relationship involving peak ground motion parameters, earthquake energy, epicentral distance and site impedence which is defined as the product of the specific soil density and specific shear wave velocity. Esteva and Rosenblueth (1964) have derived and subsequently modified relationships involving hypocentral distance and M. Donovan (1974) has derived a relationship between the same parameters and has presented a summary of the different relationships used. Seed, et al., (1968, 1969) have derived average relationships for the characteristics of bedrock motion. Schnabel and Seed (1973) studied bedrock accelerations in the western United States.

It is worth noting that two approaches are generally proposed and used for specifying the ground motion parameters: one specifies the parameters for bedrock motion at the site and incorporates the site amplification explicitly, and the other specifies the parameters for the so-called firm site and adjusts them for a particular site if that site varies significantly from the firm site condition.

The definition of a firm site is rather qualitative and includes soil condition such as soft but unfissured rock, compacted granular soils, etc. There is however a definition of firm site based on the shear wave velocity. Many researchers use 1500 ft/sec or higher shear wave velocity to imply firm site condition.

The 1974 Esteva-Rosenblueth relationship has been adopted in this work only to allow comparison between the case study presented in Chapter III and Shah, et al., (1975) where this relationship was used. Some modifications have however been introduced.

Esteva and Rosenblueth have derived the following empirical relationship between M, hypocentral distance (R_h) and peak ground acceleration by regression analysis of ground motion data.

$$a = \frac{5000 \exp(.8M)}{(R_h + 40)^2} \qquad (2.25)$$

where a = peak ground acceleration (cm/sec^2)

M = Richter magnitude

R_h = hypocentral distance (km)

The following observations regarding the Esteva-Rosenblueth relationship are pertinent:

- The seismic ground motion is highly complex in nature, and any empirical relationship, such as the one described above, can only be an approximation to the actual phenomenon. Therefore, careful judgment must be exercised to determine the applicability of this type of relationship and the associated uncertainties in its use for any given seismic region.
- This relationship is based on regression analysis of the pertinent ground motion data. Confidence intervals for the least square fit are quite wide because of a considerable data scatter. Therefore there is a high degree of uncertainty associated with the values as predicted by the relationship (Fig. 2.1).
- The relationship implies that sites located at an equal distance from the earthquake epicenter will record the same peak ground acceleration for a given earthquake. Thus the locus of equal

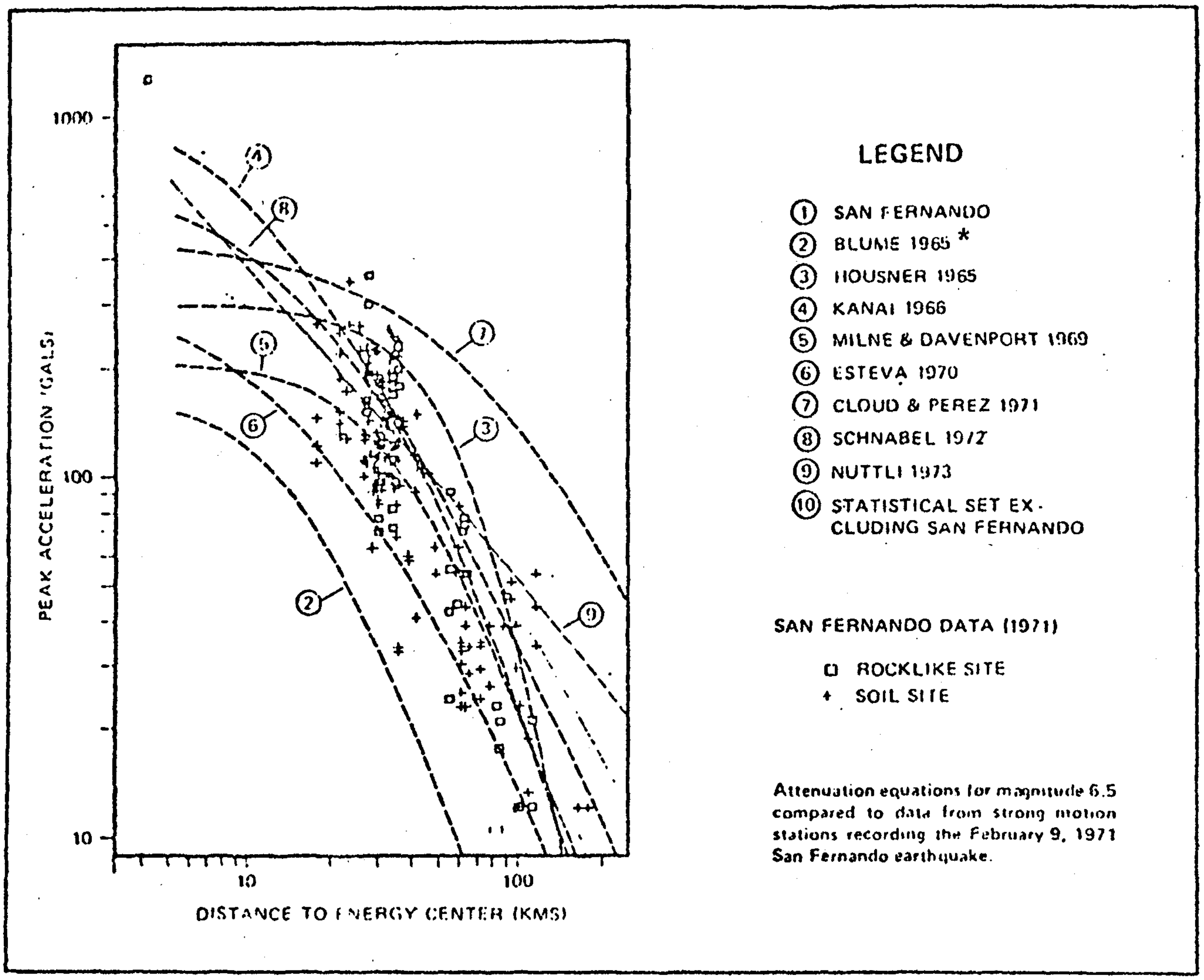

FIGURE 2.1 Attenuation Relationships.
(Donovan, 1974)

* This relation can provide results which are very close to mean data behavior if the soil characteristics for the region are recognized. The soil characteristics input was not used in the preparation of this figure.

peak ground acceleration as given by the relationship is a circle. In the case of large earthquakes which are usually associated with long fault breaks, the isoseismal contours are generally elongated and therefore almost elliptical. The Esteva-Rosenblueth relationship can be modified to incorporate the influence of extensive faulting, for example, by using the relationship between fault breakage and earthquake magnitude (Tocher, 1958). Also the isoseismal may not be circular because of the regional geological structure surrounding the site. Moreover such relationships can only be valid for larger epicentral distances. For "near source" sites use of such relationships by extrapolation gives erroneous results.

- Esteva and Rosenblueth have suggested that this relationship is applicable to firm sites only. Separate investigations should be made for sites with characteristics deviating considerably from those of the firm sites so as to appropriately incorporate the site influence (Wiggins, 1964).

The above observations regarding Esteva-Rosenblueth relationship are generally applicable for other relationships of this type and are given here to point out the limitations of such relationships.

In order to incorporate corrective measures for the first two observations mentioned above, the Esteva-Rosenblueth model is somewhat modified in the present report. Rather than using the relationship in a deterministic way as done previously, the value of an acceleration obtained for a given M and hypocentral distance is used as the mean value of a probability distribution.

The data (Fig. 2.1) does not suggest that any particular distribution is more suitable than the other. The main observation is that the scatter varies proportionally with the mean. For this reason a uniform distribution with a constant coefficient of variation is chosen.* The Esteva-Rosenblueth relationship can thus be plotted as shown in Fig. 2.2 and can be rewritten:

$$a_{mean} = \frac{5000 \exp(.8M)}{(R_h + 40)^2} \tag{2.26}$$

and for any M and R_h

$a_{max} = a_{mean} + Q_1 a_{mean} = a_{mean}(1 + Q_1)$

$a_{min} = a_{mean} - Q_1 a_{mean} = a_{mean}(1 - Q_1)$

with $0 \leq Q_1 \leq 1$.

The value of a_{max} or a_{min} can be specified by assigning the value of Q_1.

In the present study, Q_1 is chosen to take values between 0 and 0.5.

In order to simplify the treatment of PGA in the model, this quantity is treated as a discrete variable as follows. Any particular value of PGA is rounded off to the nearest multiple of 0.02 G. Hence for any given M and R_h, the distribution of PGA can be written as:

$$P(a < a_{min}) = P(a < a_{max}) = 0 \tag{2.27}$$

$$P(a = A) = 1.0/\left(\frac{a_{max} - a_{min}}{.02} + 1\right) \tag{2.28}$$

for $a_{min} \leq A \leq a_{max}$.

where A, a, a_{min} and a_{max} have been rounded off to the nearest multiple of 0.02 G.

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* In a more recent release of the model a log-normal distribution is used.

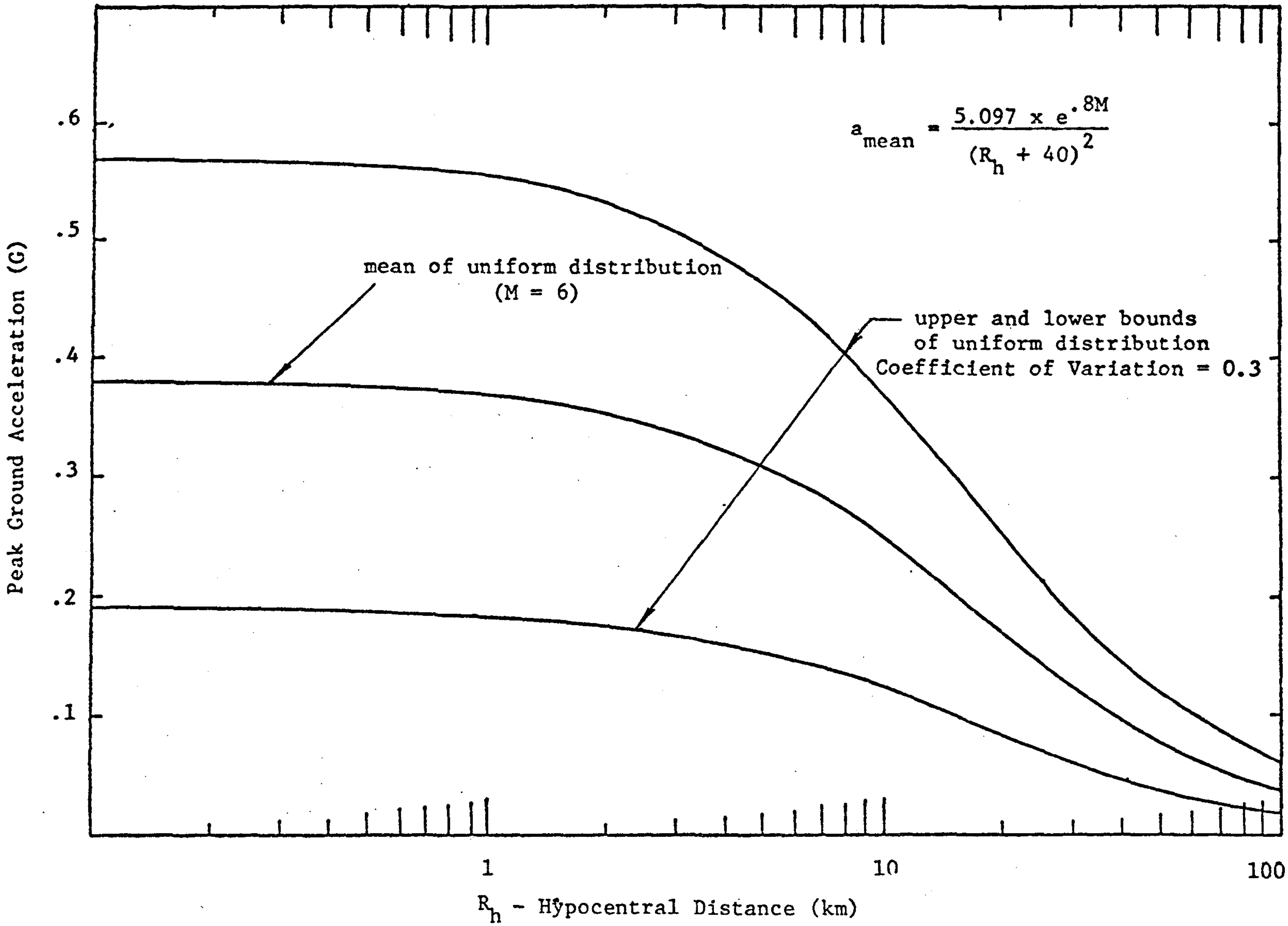


FIGURE 2.2. Esteva Attenuation Relationship with Uniform Distribution

2.4.3 Relation between Richter Magnitude and Duration

The duration parameter d of strong seismic shaking has not been investigated to any great extent. Its prediction from records is still rather rudimentary even though "duration is possibly the single most important factor in producing excessive damage" (H. M. Engle, in Richter, 1958). However several relationships have been presented.

Housner's (1965) relationship for "the strong phase of ground shaking" is essentially a linear law in terms of magnitude M

$$d = 11\,M - 53 \qquad M \geq 5 \qquad (2.29)$$

where d = duration (sec)

M = Richter magnitude

Esteva-Rosenblueth (1964) define the duration s of an "equivalent" ground motion with uniform intensity per unit time as:

$$s = 0.02\,\exp(0.74M) + 0.3r \qquad (2.30)$$

where s = equivalent duration (sec)

M = Richter magnitude

r = distance from source (km)

For large M, this duration s is about half the duration d presented in equation 2.29.

The following quotation is applicable: "These formulae do express the key dependence of d and M which can be inferred at once from the rupture model of earthquakes. What the formulae lack is a stated threshold of ground acceleration a to define "strong" and a treatment of frequency" (Bolt, 1973).

Two definitions of duration appear to be useful:

(A) "Duration at particular frequency is the elapsed time between the first and last acceleration excursions greater than a given level (say 0.05 or 0.02 G). Bolt calls this interval the "bracketed duration". It is sometimes measured by cumulatively adding the squared accelerations and adopting the 95 percentile time interval (Husid, et al., 1969). However, particularly for earthquakes with a complex multiple source (Wyss and Brune, 1967), this definition often leads to a non-physical upper estimate. Trifunac (1976) and Dobry, et al., (1977) adopt this type of approach to obtain duration of earthquake records.

(B) "Duration at a particular frequency is the total time for which acceleration at that frequency exceeds a given value". This interval called "uniform duration" by Bolt, may equal the corresponding "bracketed duration" or be much less. Uniform duration appearsto have a greater mechanical significance with respect to actual structural response behavior.

The treatment of duration in this part of the dissertation is inspired by the paper "Duration of Strong Motion" by B. A. Bolt. Fifth World Conference on Earthquake Engineering, Rome, (1973).

Table 2.1 is reproduced from this paper. It gives the duration (sec) of earthquakes as a function of M and distance (km) from the source. Bolt asserts that observational data scatter indicates that the chance of exceeding the tabulated values by 20% or more is about 0.1. This implies that the coefficient of variation is about 0.15. The values given in Table 2.1 are plotted in Fig. 2.3.

The following expressions fit the data conservatively

$$d = d_{50} + .15(50 - R_h) \tag{2.31}$$

for $5 \leq R_h \leq 50$

$$d = d_{50}/(.00112(R_h - 50)^2 + 1) \tag{2.32}$$

for $R_h \geq 50$

where d = duration (sec)

d_{50} = duration (sec) at 50 km from the source for the M considered

R_h = hypocentral distance (km)

distance \ M	5.5	6.0	6.5	7.0	7.5	8.0	8.5
10	8	12	19	26	31	34	35
25	4	9	15	24	28	30	32
50	2	3	10	22	26	28	29
75	1	1	5	10	14	16	17
100	0	0	1	4	5	6	7
125	0	0	1	2	2	3	3
150	0	0	0	1	2	2	3
175	0	0	0	0	1	2	2
200	0	0	0	0	0	1	2

TABLE 2.1 Bracketed Duration (sec) (Acc $\geq$ 0.05g; freq $\geq$ 2 Hz)
distance = distance from source (km).

Reproduced from Bolt (1973).

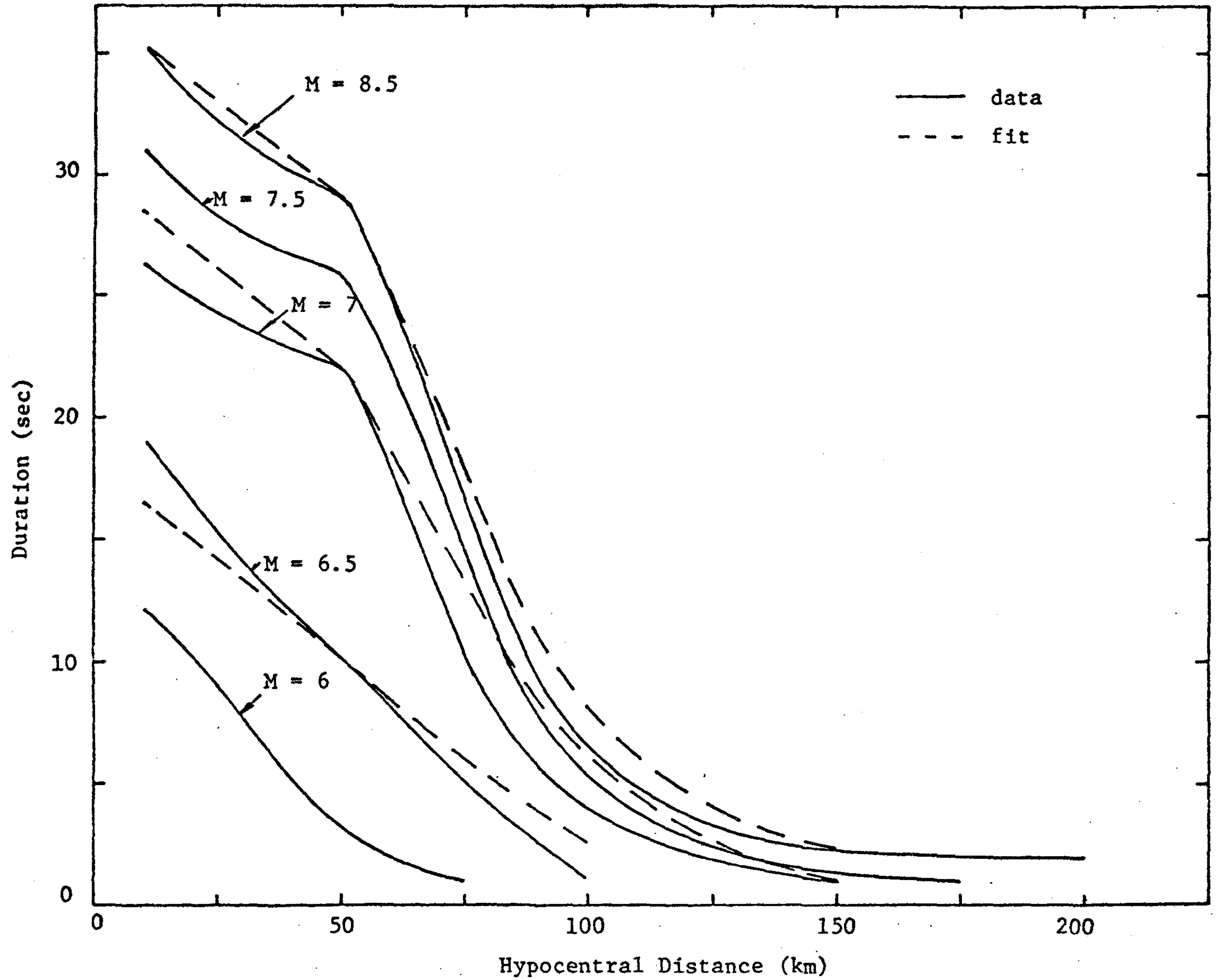


FIGURE 2.3. Bracketed Duration

The durations for different magnitudes at 50 km from the source (d_{50}) are given in Table 2.2 and are plotted in Figure 2.4. They are obtained directly from Table 2.1 using interpolation when the M is missing. They are the base values in the above expressions.

The observations listed in Section 2.4.2 regarding the Esteva-Rosenblueth relationship apply to this relation as well since this duration relationship has been obtained using the same method and the right hand side of the expression contains the same type of parameters. For this reason, the duration is also treated as a random variable with uniform distribution.* The mean is obtained from the above expressions (Eq. 2.31 and 2.32) and the coefficient of variation is kept constant. For any M and R_h, d_{mean} is given from the equations 2.31 and 2.32 where d_{50} is obtained from Table 2.2. The upper and lower bounds of the uniform distribution can be written

$$d_{max} = d_{mean} + Q_2 d_{mean} = d_{mean}(1 + Q_2)$$
$$d_{min} = d_{mean} - Q_2 d_{mean} = d_{mean}(1 - Q_2)$$
$$\text{with } 0 \leq Q_2 \leq 1$$

where the values of d_{max} and d_{min} can be specified by assigning the value of Q_2.

In the present study Q_2 is chosen to take values between 0 and 0.5.

In order to simplify the treatment of duration in the model this quantity is treated as a discrete variable as follows. Any particular value of d is rounded off to the nearest multiple of 2 seconds. Hence for any given M and R_h the distribution of durations can be written as

---

* In a more recent release of the model a log-normal distribution is used.

Duration (sec)	M
1.5	4.0
1.5	4.25
1.5	4.50
1.5	4.75
2.0	5.0
2.0	5.25
2.0	5.50
2.5	5.75
3.0	6.0
5.5	6.25
10.0	6.50
17.0	6.75
22.0	7.0
24.25	7.25
26.0	7.50
27.25	7.75
28.0	8.0
28.5	8.25
29.0	8.50
29.5	8.75
29.5	9.0

TABLE 2.2 Bracketed Duration (sec) at 50 km from source (Acc $\geq$ 0.05 g; freq. $\geq$ 2 Hz)

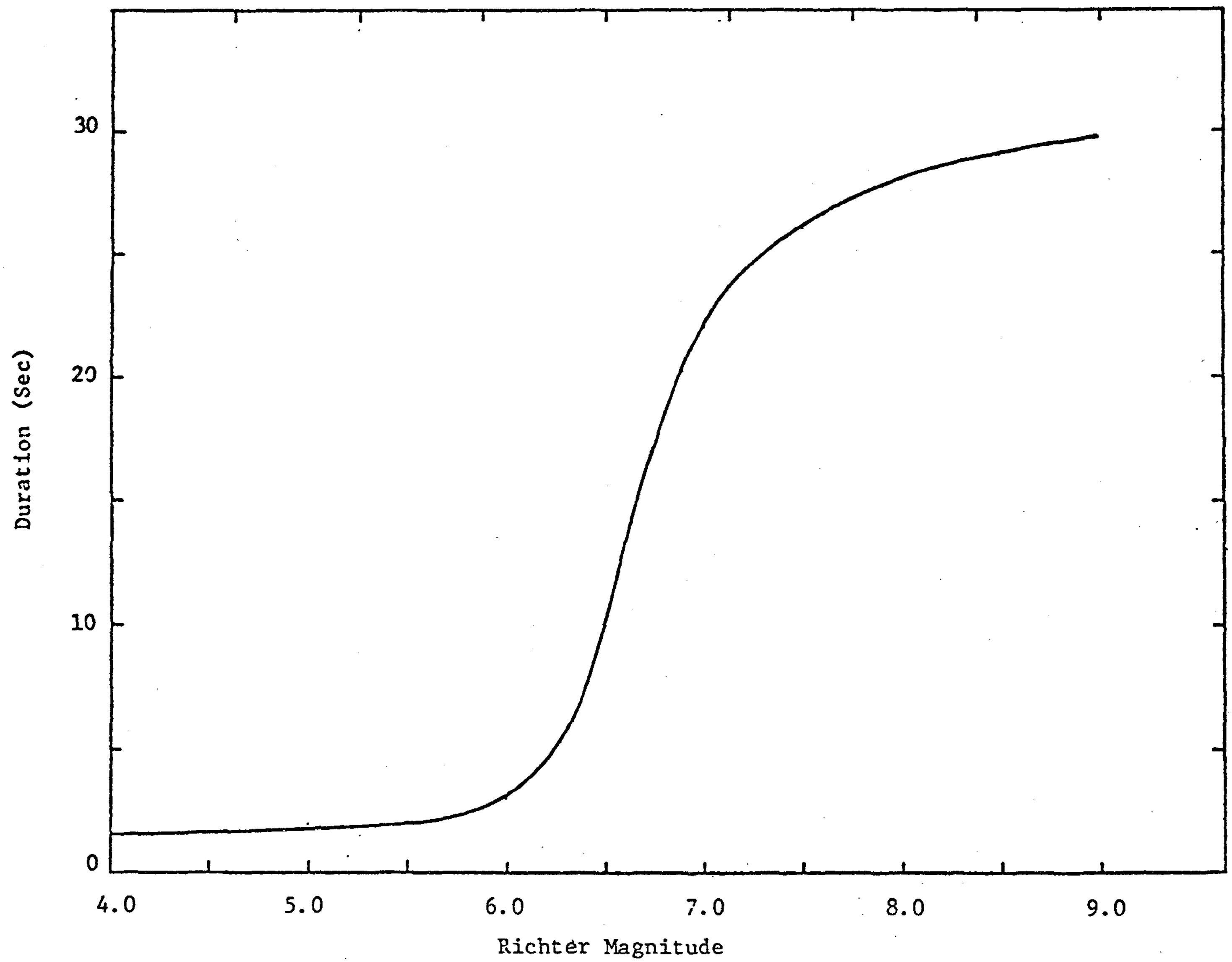


FIGURE 2.4. Bracketed Duration at 50 km from Hypocenter

$$P(d < d_{min}) = P(d > d_{max}) = 0 \tag{2.33}$$

$$P(d = D) = 1/(\frac{d_{max} - d_{min}}{2} + 1) \tag{2.34}$$

for $d_{min} \leq D \leq d_{max}$

where D, d, d_{min} and d_{max} have been rounded off to the nearest multiple 2 seconds.

2.5 Probabilistic Estimation of Peak Ground Acceleration and Duration

2.5.1 Introduction

Up to this point, the following steps have been discussed and developed:

- The seismic sources that can affect a site under consideration have been located. They can be line sources or area sources.
- The seismicity of each source (considered homogeneous over the source) has been determined. It is described in terms of the probability of occurrences of any number of events of any Richter Magnitude (M_i) for a given period of time. Bayesian concept is applied in this part of the analysis.
- Two attenuation equations have been chosen to convey the information from the sources to the site. The parameters chosen to describe the seismicity at the site are the peak ground acceleration and the duration of the shaking.

In general a site is surrounded by a number of sources. For design purposes, the probabilistic loading at the site is obtained by combining the effect of all the sources. The loading is expressed in terms of the probability of occurrence of at least one event of a given PGA and the probability of at least one event of a given duration. Probability distribution functions or cumulative distribution functions for these two parameters are developed for each site for a given time period t. These two distributions totally describe the seismicity of the site in terms of the chosen parameters.

2.5.2 Contribution of a Segment

All the quantities (M, PGA, duration) used in the Section 2.4 are discretized to equal step increments. Hence, all the integral signs can be replaced by summations. Since the hypocentral distance is a parameter in both attenuation relationships the seismic source (usually a line or an area) must be divided into segments ΔL or ΔA to take into consideration the distance variation to the site from the source. The size of the segments is chosen small enough such that the approximation from a continuous to discrete computation is acceptable. The seismicity within a source remains the same from segment to segment. It is easily obtained from the data gathered for each source. The mean rate of occurrence of events (eq. 2.9) for the whole source becomes for a segment:

$$\lambda''' = (\lambda'' \cdot \Delta L)/L \qquad (2.35)$$

where L = length or area of source

ΔL = length or area of segment.

The distribution on the number of events for each segment is obtained from equation 2.9 where λ'' is replaced by λ'''. The conditional distribution on magnitudes given M events (eq. 2.20) remains unchanged by the segmentation of the sources. The distribution of the number of occurrences of each magnitude is given by equation 2.21. The probability of zero occurrence of each magnitude is given by equation 2.22. The same distribution applies for any segment of the source. The distribution of the number of occurrences of each M increment can be presented under a matrix form that describes the total seismicity of the segment (Table 2.3.).

Only a finite number of different magnitude events can occur on the segment (from the largest to the smallest magnitude considered). The number of occurrence associated with them. They are disregarded when this probability becomes negligible, say 10^{-8}. Hence the total number of events is finite and can easily be handled under the summation signs.

Since the distance from the segment to the site is known, all the parameters of the attenuation relationships (Eq. 2.26, 2.31, 2.32) are determined. Hence, for each M a uniform distribution on acceleration is obtained as follows:

$$a_{mean} = \frac{5000\ e^{.8M}}{(R_h + 40)^2} \tag{2.36}$$

a_{min} and a_{max} are determined from the coefficient of variation and rounded off to the closest multiple of 0.02 G.

The contribution to acceleration greater or equal to a_i of all events M_j occurring on the same segment is written as:

$$P(A \geq a_i) = p \times P(M_j) + \left[1 - (1 - p)^2\right] P(2M_j) + \ldots + \left[1 - (1 - p)^n\right] P(nM_j) \tag{2.37}$$

Number of Occurrences		Richter Magnitude							
		4.0	4.25	4.50	4.75	--	--	M_i	--
	0								
	1								
	2								
	3							$P(3M_i)$	
	:								
	:								
	:								
	n							$P(nM_i)$	
	:								
	:								

TABLE 2.3. Seismicity of a Segment.
Probability of occurrence of any number of events of given M_i.

where: $P(A \geq a_i)$ = probability of obtaining acceleration greater or equal to a_i at least once.

$P(kM_j)$ = probability of k occurrences of event M_j with $k = 1, 2 \ldots n$

$p = P(A \geq a_i/M_j)$, probability of obtaining an acceleration greater or equal to a_i given an event M_j

Setting $q = 1 - p$, the above expression can be rewritten:

$$P(A \geq a_i) = (1 - q)\ P(M_j) + (1 - q^2)\ P(2M_j) + \ldots + (1 - q^n)\ P(nM_j)$$

$$= P(M_j) + P(2M_j) + \ldots + P(nM_j) -$$

$$q\ P(M_j) - q^2\ P(2M_j) - \ldots - q^n\ P(nM_j) \tag{2.38}$$

$$P(A \geq a_i) = 1 - P(\text{no } M_j) - \sum_{k=1}^{n} q^k\ P(kM_j) \tag{2.39}$$

$$P(A \leq a_i) = P(\text{no } M_j) + \sum_{k=1}^{n} q^k\ P(kM_j) \tag{2.40}$$

with n chosen such that $q^k P(nM_j)$ can be neglected.

The above discussion assumes independence among events. Hence, the contribution of all possible events can be combined as follows:

$$P(A \geq a_i)\Big|_{\text{one segment}} = 1 - \prod_{\substack{\text{all}\\ M_j}} \Big[1 - P(A \geq a_i)_{M_j}\Big] \tag{2.41}$$

The whole range of magnitudes is covered starting with the largest one down to the smallest one that generates a noticeable effect at the site ($M_j \geq M_{min}$ as a function of distance). This eliminates the consideration of a large number of events.

Similarly for duration

$$d_{mean} = d_{50} + .15(50 - R_h) \qquad R_h \leq 50 \text{ km} \qquad (2.42a)$$

$$= \frac{d_{50}}{(.00112(R_h-50)^2 + 1)} \qquad R_h \geq 50 \text{ km} \qquad (2.42b)$$

d_{min} and d_{max} are determined from the coefficient of variation and rounded off to the closest multiple of 2 seconds.

$$P(D \leq d_i) = P(\text{no } M_j) + \sum_{k=1}^{r} q^k \, P(kM_j) \qquad (2.43)$$

with n chosen such that q^i $P(n\ M_j)$ can be neglected.

where: $P(D \geq d_i)$ = probability of obtaining duration greater or equal to d_i at least once.

$P(k\ M_j)$ = probability of k occurrences of event M_j with k = 1, 2, . . .n

$p = 1-q = P(D \geq d_i/M_j)$, probability of obtaining an acceleration greater or equal to d_i given an event M_j

and

$$P(D \geq d_i)\Big|_{\text{one segment}} = 1 - \prod_{\text{all } M_j} \left[1 - P(D \geq d_i)_{M_j} \right] \qquad (2.44)$$

2.5.3 Contribution of One or Several Sources

As the events are assumed independent from segment to segment, the contribution of each segment of a source is combined as in equation 2.41 and 2.43.

$$P(A \geq a_i)\Big|_{\text{one source}} = 1 - \prod_{\substack{\text{all} \\ \text{segments}}} \left[1 - P(A \geq a_i)\Big|_{\substack{\text{one} \\ \text{segment}}}\right] \qquad (2.44a)$$

$$P(D \geq d_i)\Big|_{\text{one source}} = 1 - \prod_{\substack{\text{all} \\ \text{segments}}} \left[1 - P(D \geq a_i)\Big|_{\substack{\text{one} \\ \text{segment}}}\right] \qquad (2.44b)$$

The seismicity at the site in terms of probability of occurrence of each PGA value at least one time and each duration at least one time can be described by the two vectors in Table 2.4.

When several sources are considered, the same principle is applied for each source. Thus,

$$P(A \geq a_i) = 1 - \prod_{\substack{\text{all} \\ \text{sources}}} \left[1 - P(A \geq a_i)\Big|_{\substack{\text{one} \\ \text{source}}}\right] \qquad (2.45a)$$

$$P(D \geq d_i) = 1 - \prod_{\substack{\text{all} \\ \text{sources}}} \left[1 - P(D \geq d_i)\Big|_{\substack{\text{one} \\ \text{source}}}\right] \qquad (2.45b)$$

These expressions give the probability of occurrence at the site of at least one acceleration and at least one duration greater than a given level.

Once a cumulative distribution function is established for each node of a grid, a seismic exposure map can be prepared for any desired probability of nonexceedence. Smothing procedures are used to obtain smooth contours at given intervals.

Such maps can be drawn for any of the parameters of interest. A detailed procedure for such a hazard mapping is given in Chapter III for the peak ground acceleration and duration. However, the methodology developed here is general enough that a map for spectral responses can be obtained if the attenuation information for such response parameters is known.

PGA (G)	Prob of at least one occurrence
0	
.02	
.04	
.06	
:	
:	
a_i	
:	
:	
a_n	

Duration (Sec)	Prob of at least one occurrence
0	
2	
4	
6	
:	
:	
d_i	
:	
:	
a_m	

TABLE 2.4. Probability of at least one occurrence of any PGA a_i.

Probability of at least one occurrence of any duration d_i.

CHAPTER III

APPLICATION TO NICARAGUA

3.1 Introduction

In this chapter seismic hazard maps are developed for Nicaragua using the model presented in Chapter II. Each step of the methodology is covered in the example:

- gathering of the available data
- location of the seismic sources
- Bayesian description of the seismicity
- use of probabilistic attenuation relationships
- development of iso-duration and iso-acceleration maps

This case study is presented to emphasize the following points:

- the simplicity of incorporating any subjective information with the historical data to obtain Bayesian estimation on fault seismicity.
- the versatility of the method in which various uncertainties can be incorporated in the attenuation relationships
- the similarity between the results obtained with this model and the ones presented in Shah, et al., (1975)*.

3.2 Seismic Data Base for Nicaragua

The earthquake data used in this study is the same as the data used in Shah, et al. (1975). Two main sourcesof information are considered. The NEIC-NOAA data file covering the period from January 1900 to August 1973 constitutes the primary source of information and is referred to hereafter as Source 1. The Catalogue of Nicaraguan Earthquakes, 1520-1973, by David J. Leeds (1973), is referred to as Source 2. The latter

* In the following pages, continuous reference is made to "A Study of Seismic Risk for Nicaragua, Part I", Shah, et al. (1975). It might be advantageous to the reader to make himself familiar with Chapters I through V of this publication.

is used to obtain:

- data about earthquakes not reported or incompletely reported in the NEIC-NOAA file (1900-1973);
- data about earthquakes associated with volcanic activity along the Cordillera de los Marrabios (1850-1973).

The data covering the period from 1520 to 1850 is not considered in the analysis. This information is mainly descriptive, of low reliability and difficulty evaluable in terms of presently used parameters. Moverover, it is biased in that sense that only few large events situated close to populated areas have been recorded. Hence, it cannot be used as such together with more homogeneous and better quality data. However its historical interest should not be neglected and could be used, for example, to help the analyst in formulating his subjective input. The time period of data gathering is thus 73 years for the entire country and 123 years for earthquakes associated with volcanic activity along the Cordillera de los Marrabios.

In spite of the complimentarity of the two sources, a large number of events remain insufficiently documented to be used as such in the analysis. Rather than disregarding these events, the missing information is generated using a Monte Carlo process supplemented by judgment. It is felt that the total analysis benefits more than suffers from such an additional input.

The following remarks are valid for both sources:

- No critical study is made regarding the validity of the information and the reliability of the data.
- Whenever information as basic as epicentral location or magnitude is missing, the event is disregarded.

- Events with Richter magnitude smaller than 3.0 are not considered.

Source 1

When complete, the information contained in this source includes for a given event: time of occurrence, epicentral location (degrees), depth of hypocenter (km), and magnitude. The magnitude is in terms of one of the following:

(1) CGS M_b average (Coastal Geodetic Survey body wave magnitude)

(2) CGS M_s average (Coastal Geodetic Survey surface wave magnitude)

(3) Richter magnitude M.

The acceleration attenuation relationships used in Chapter II are based on the Richter magnitude. Hence, when missing, this information is generated from M_b or M_s. It is known that for a given part of the world, the Richter magnitude and CGS M_b are linearly related such that

$$M = a + b\, M_b \tag{3.1}$$

In order to determine the coefficients a and b, a regression analysis is run for all the earthquakes of which M and M_b are known using the total data of Central America. The Richter magnitude is then obtained by substituting the value of M_b in equation 3.1.

Whenever data on depth of hypocenter are not available, a depth is assigned, as will be explained later in the chapter.

From Source 1, 419 events contain complete information; they are shown as a function of depth in Table 3.1.

Source 2

When complete, the information contained in this source includes for a given event: time of occurrence, epicenter location (degrees), depth, Richter magnitude and sometimes a short description of the seismic event. The depth is either expressed in km or by a letter symbol N (0 - 60 km) or I (70 - 200 km). In the same way, the Richter magnitude is either expressed by its numerical value or by a letter symbol, as follows:

B - $7 \leq M \leq 7.7$

C - $6 \leq M \leq 6.9$

D - $5.3 \leq M \leq 5.9$

E $M < 5.3$

Through a simulation process, all the events taken from Source 2 are assigned a numerical Richter magnitude from letter magnitude.

Hence, an additional 196 events are obtained (including events from Source 1 with partial information), distributed as follows:

43 events associated with volcanic activity and with shallow hypocenters N (0 - 60 km).

40 events with shallow hypocenters N (0 - 60 km).

3 events with deep hypocenters I (70 - 200 km).

63 events with no data on depth.

47 events with numerical data on depth (km).

The 466 earthquakes with complete data (419 from Source 1 and 47 from Source 2), are plotted as a function of depth. Using those plots together with epicenter location, magnitude value, partial information on depth and judgment, the 149 remaining events are assigned appropriate depths. This led to a total data of 615 events ranging from

TABLE 3.1

Data from Source 1, Sorted According to Depth of Hypocenter
(419 Events)

Number of Earthquakes	Depth Range (km)
8	0 - 9
9	10 - 19
12	20 - 29
157	30 - 39
35	40 - 49
32	50 - 59
34	60 - 69
32	70 - 79
18	80 - 89
14	90 - 99
13	100 - 109
9	110 - 119
3	120 - 129
7	130 - 139
3	140 - 149
7	150 - 159
3	160 - 169
6	170 - 179
3	180 - 189
5	190 - 199
9	200 - 215

5 to 215 km in depth and from 3.0 to 7.7 in magnitude. Appendix A gives the listing of those earthquakes. In Figures 3.1 through 3.6 (Charts 2 through 7 from Shah, et al., 1975), they are plotted as a function of depth.

From these figures the general seismic pattern of Nicaragua can be divided into the following regions:

(1) The Benioff Zone dipping North East toward the Nicaraguan coast. This zone is marked by numerous earthquakes covering the whole range of magnitude (larger as depth increases) and extending several hundred kilometers into the earth's interior. The shallow earthquakes ($\sim$ 30 km) due to this source are from 30 to 100 km away from the coast. As the epicenters get closer to the coast, the hypocenters get deeper. Hence, under Managua the hypocenters of earthquakes situated on the Benioff Zone are very deep (100 - 200 km).

(2) In contrast, for the local seismic sources, such as the ones identified under Managua, the hypocenters are shallow (5 - 30 km). In magnitude scale, these sources do not generate major earthquakes such as those on the Benioff Zone. However, due to their shallowness and proximity to populated areas, they have caused extensive damage and loss of life in past history. The December 23, 1972 event was due to the local source under Managua.

(3) The line of volcanoes from Northwest to Southeast (Cordillera de los Marrabios) represents sources of future seismic activities. Volcanic eruptions are seldom by themselves sources of seismic activity, and in the past various earthquakes have been recorded preceding volcanic eruptions. For this reason earthquakes "associated" with volcanic activity were treated in the model as shallow tectonic earthquakes.

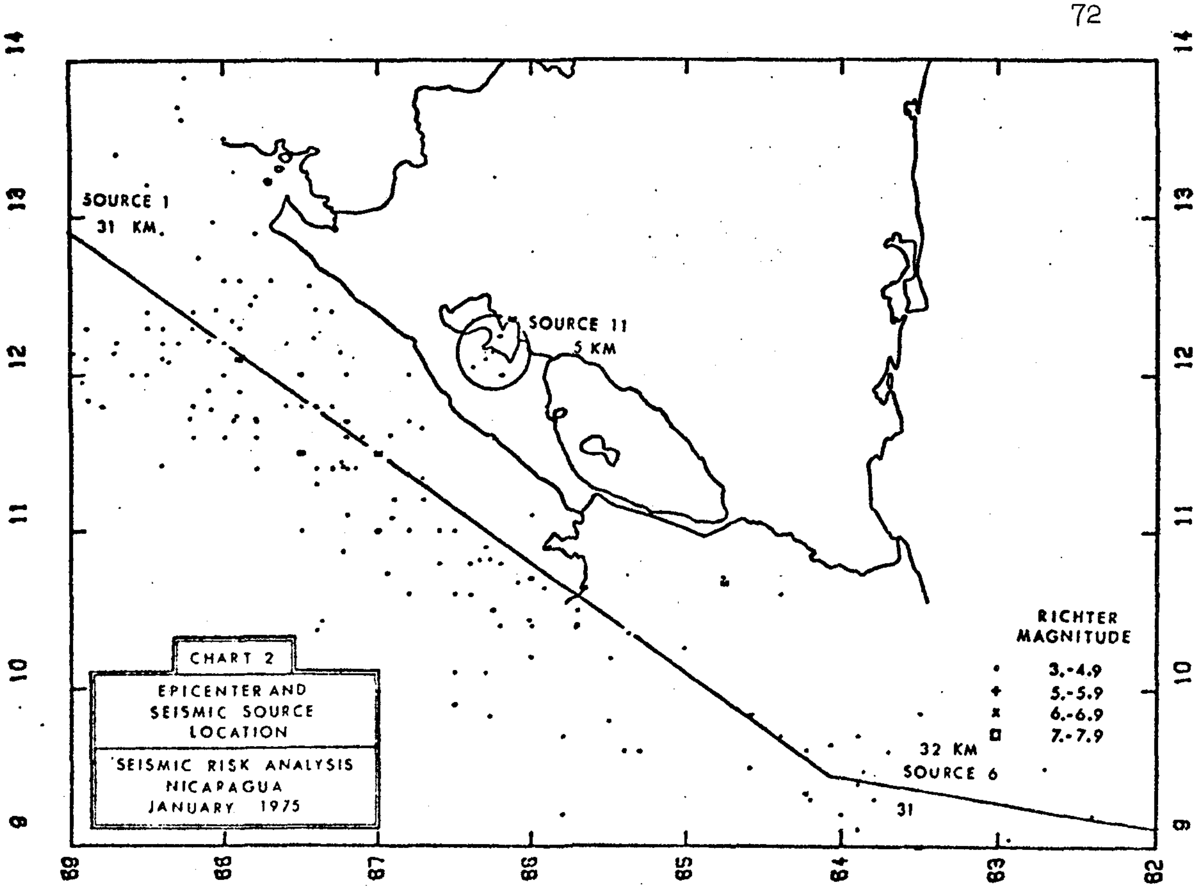


FIGURE 3.1

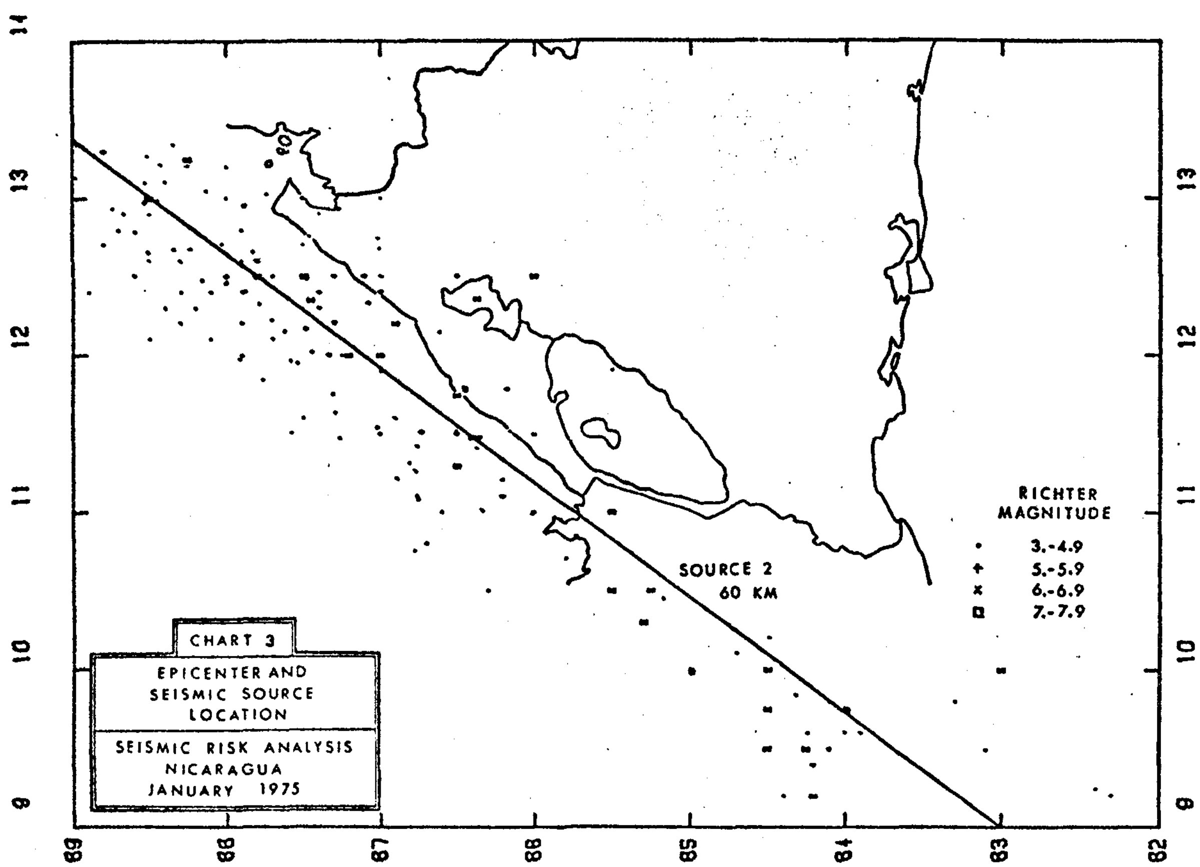


FIGURE 3.2

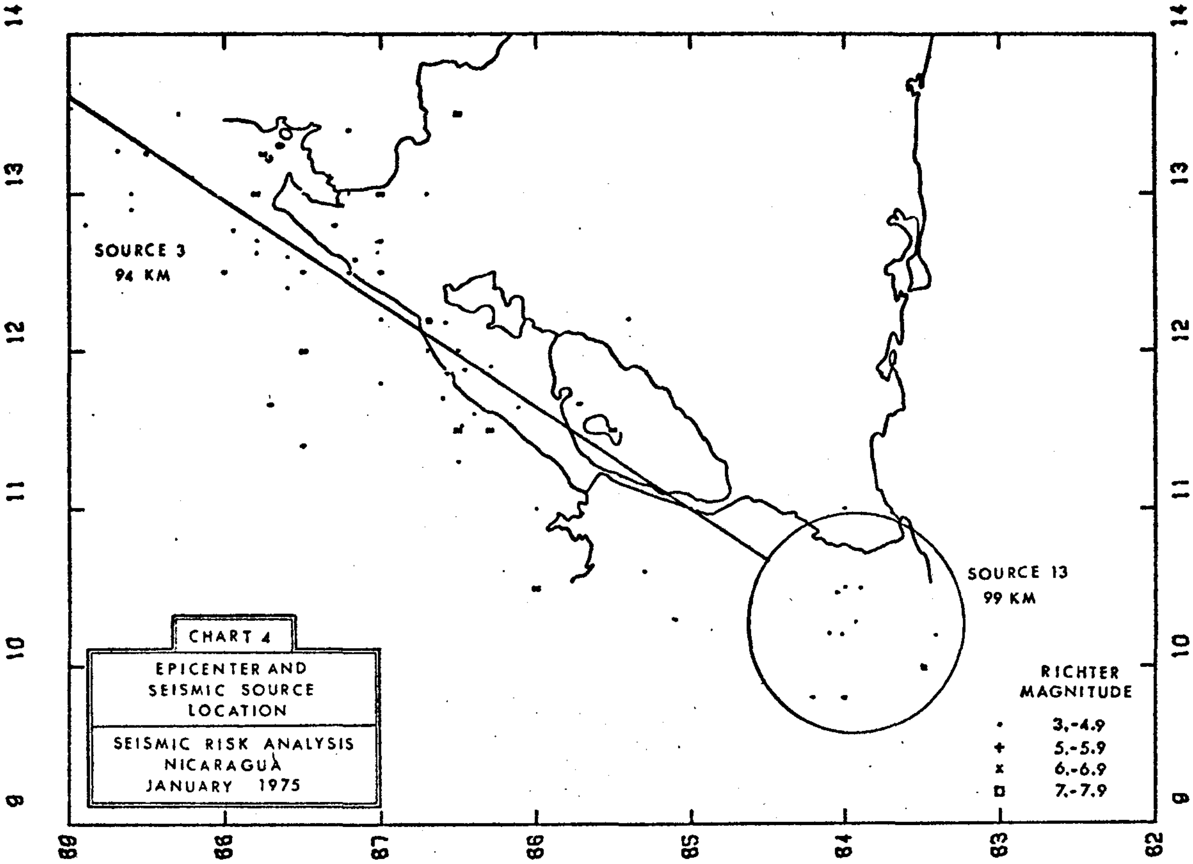


FIGURE 3.3

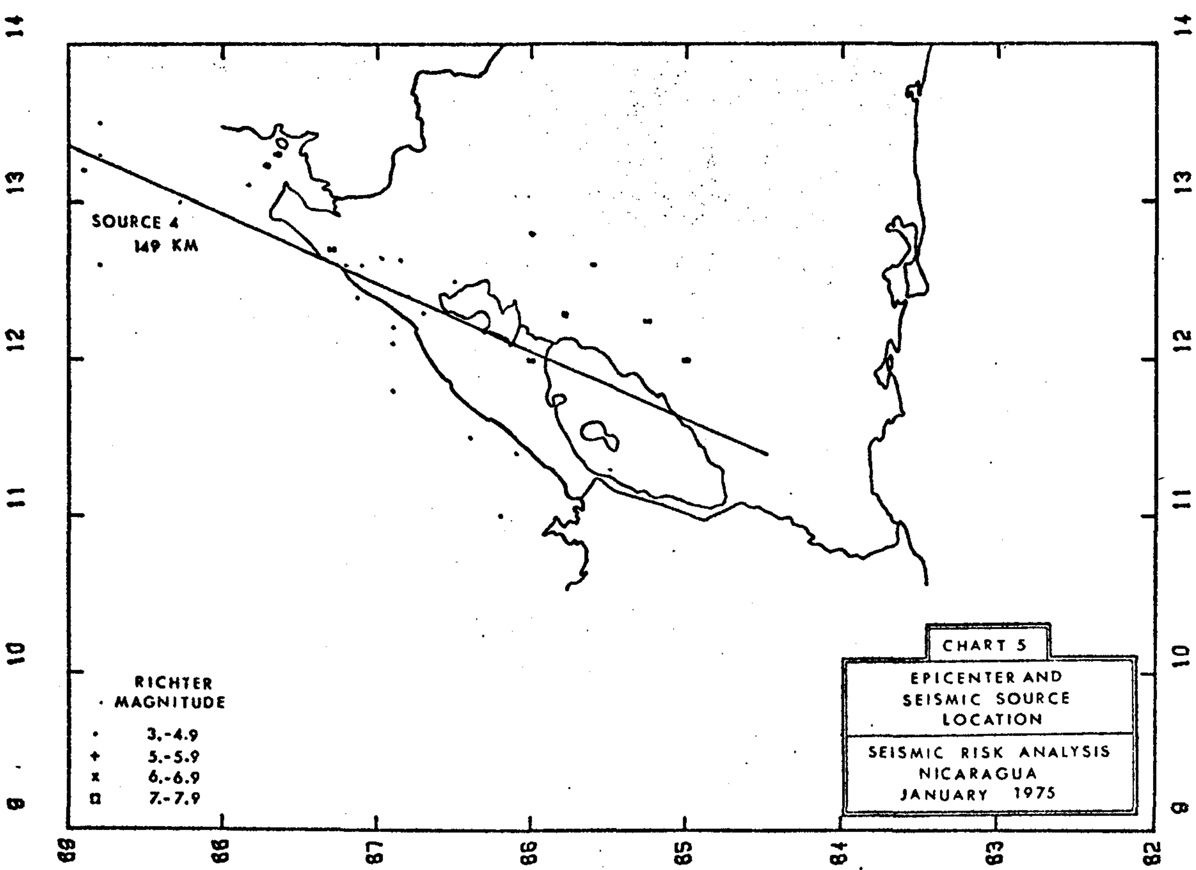


FIGURE 3.4

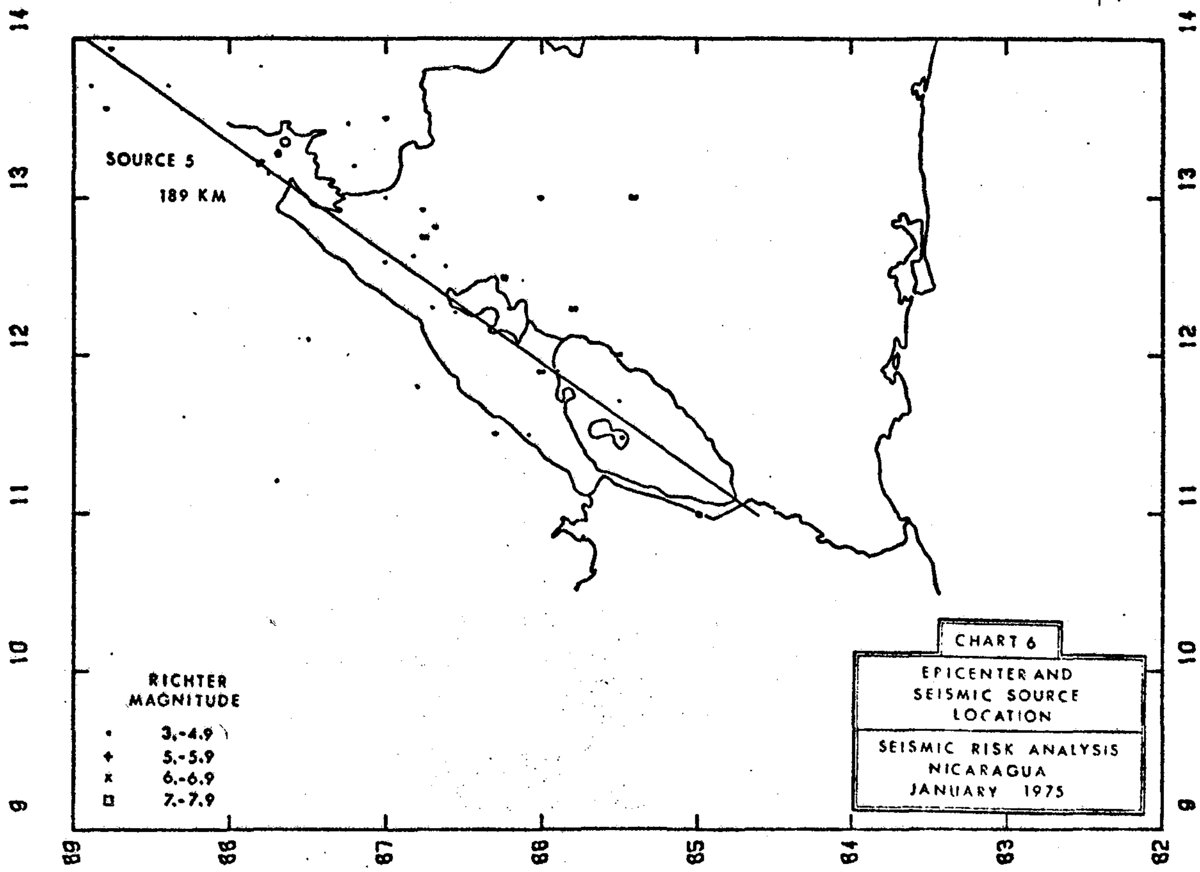


FIGURE 3.5

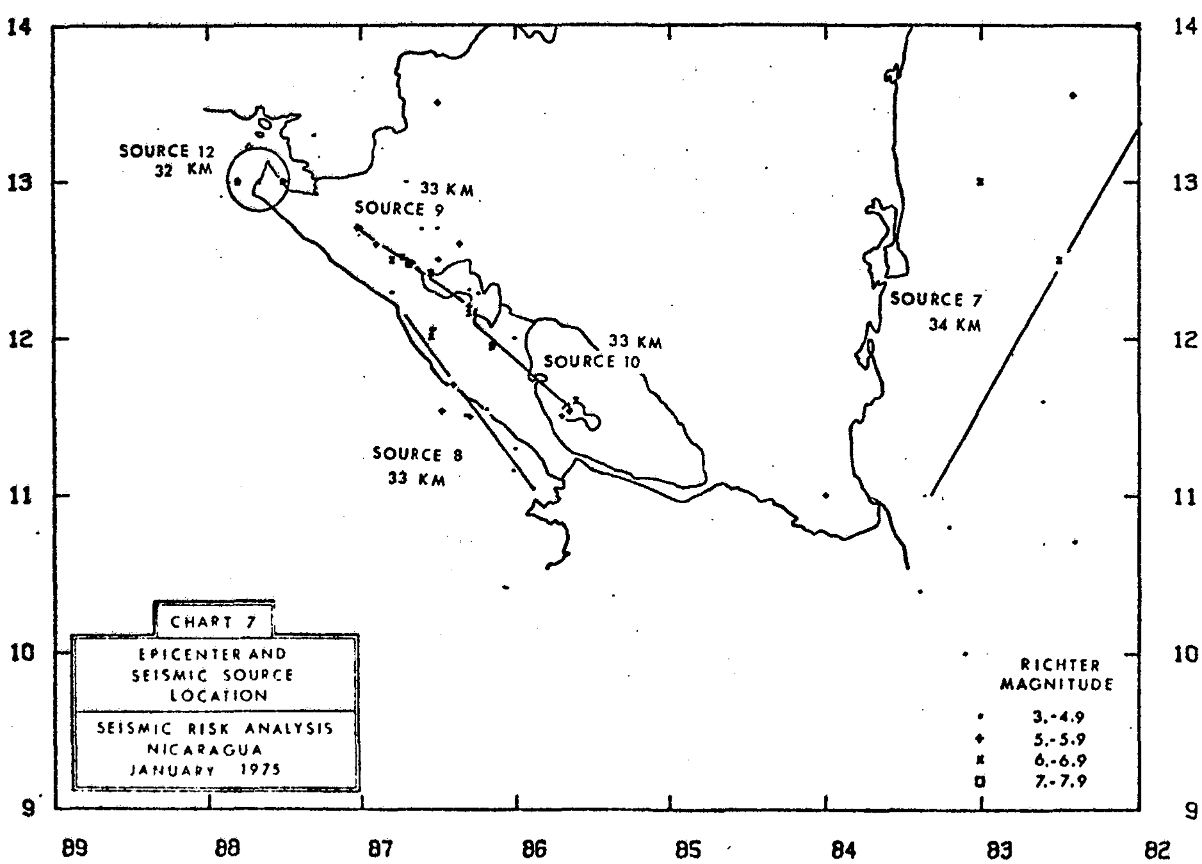


FIGURE 3.6

(4) Two shallow (~30 km) seismic regions, one more or less coinciding with the Pacific seashore between Lake Managua and the Costa Rica border, the other one in the Gulf of Fonseca.

(5) The Atlantic coast of low seismicity.

Source Location and Seismicity

Based on the above observations, the total number of events is divided into 13 seismic sources: Ten of these are line sources and three are area sources. Table 3.2 shows these 13 sources, the number of events and the depth range of each source.

Appendix A gives a listing of the earthquakes included in each source. Line sources are located by fitting a line through the data using regression analysis. For area sources, the centroid is obtained from the data and the radius taken as the distance from the centroid to the most distant epicenter in the source.

The depth of each source is computed as an average hypocentral depth of all the earthquakes included in the source. Earthquakes with no or limited depth information are not included in this averaging process. However, they are considered in determining the location and the seismicity of the sources. Figures 3.1 through 3.6 show the sources locations and depths.

Limitations

It can be said that there are limitations to the use of available data for the Nicaragua region. These limitations are given below.

TABLE 3.2

Seismic Sources for Nicaragua

Source	Number of Events	Names of Source	Depth (km.)
1 Line	159	Benioff	5 - 39
2 Line	186	Benioff & Costa Rica	40 - 79
3 Line	72	Benioff	80 - 109
4 Line	31	Benioff	110 - 159
5 Line	41	Benioff	160 - 215
6 Line	23	"Costa Rica"	5 - 39
7 Line	11	Atlantic	All Depths
8 Line	12	Pacific Coast Line	33
9 Line	57	Line of Volcanoes	33
10 Line	57	Line of Volcanoes	33
11 Area	5	Managua Area	5
12 Area	8	Gulf of Fonseca	33
13 Area	10	Costa Rica Area	80 - 109

1. 24% of the data contain incomplete information regarding the depth. This information was added from either judgment or by correlating the event with other data where the depth information was available.

2. 32% of the data have magnitude defined by a symbol. Numerical value of magnitude for these cases was obtained through simulation.

3. The reliability of the total data base was not evaluated.

(i) Some information was obtained from church and historical records.

(ii) Distribution of information over the country is biased. Populated areas have better records than sparsely populated areas. (No population $\rightarrow$ no records.)

(iii) Epicentral location could be in error due to lack of a good grid of recording system. It is hoped that the recording network presently installed by the Nicaraguan authorities, the U.S.G.S. and private organizations in Nicaragua will help in increasing the understanding of attenuation relationships and the accuracy of epicentral locations in the future. Such calibration may help in relocating the past events (Dewey, 1973).

It is felt that the work done by Dewey (1973) and others in calibrating the epicentral locations through the ESSO refinery record does not have sufficient experimental evidence as yet. Hence, no hypocenters are moved based on Dewey's work. (One exception is the 1931 earthquake-stadium fault.)

The above remarks point out the need for using the Bayesian model which can help to supplement the incompleteness of the data with subjective information.

3.3 Data Analysis and Subjective Input

As mentioned previously, the Richter magnitude is treated as a discrete variable. Its values are rounded off to the closest multiple of .25 on the Richter magnitude scale. These rounded off values are referred thereafter as M_i's (4.0; 4.25; 4.5; 4.75; etc.). Events of M_i smaller than 4.0 are not considered in the model (although they are used in obtaining the subjective information on occurrences). Events of M_i smaller than 3.0 are totally disregarded.

The data is analyzed in two steps. In the first step information is obtained to determine the rate of occurrence of events independently of magnitude. This is used as an input to the Poisson-gamma model. In the second step information is gathered about the distribution of magnitudes of these events. For each M_i the probability of success given one trial is determined. A trial is defined as the occurrence of an earthquake. A success is defined as the earthquake being of the M_i considered while a failure is defined as the earthquake being of any other magnitude. This is used as the input to the Bernoulli-Beta model.

The analysis is based on two sources of information: the available data as presented in Appendix A and the subjective input introduced through Bayesian analysis. In order to make the comparison with Shah, et al. (1975), more meaningful, the subjective input is arbitrarily chosen as the input used for that study. One has to remember that one goal of the case study is to compare the behavior of the model developed in this dissertation with the other available models. This can only be done if the data used in comparing the two models is similar. The values of all the parameters used for the 13 sources are listed in Tables 3.3 through 3.14.

TABLE 3.3
Seismic Source Parameters

Source 1 (line)
Benioff (5 - 39 km)

Time Data Base (T): 73 years
Number of Recorded Events (N): 82
ν' from log-linear fit : 72
$\lambda'' = \lambda' + T = 73 + 73 = 146$
$\nu'' = \nu' + N = 72 + 82 = 154$
$\eta''_{M_i} = \eta'_{M_i} + N = 72 + 82 = 154$

Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit Fig. 3.7) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
4.0	26	72.0	18.0	44.0
4.25	18	54.0	12.0	30.0
4.50	14	42.0	11.0	25.0
4.75	4	31.0	7.0	11.0
5.0	2	24.0	4.5	7.5
5.25	4	18.5	4.5	8.5
5.50	3	14.0	3.5	6.5
5.75	6	10.5	2.3	8.3
6.0	2	8.2	2.0	4.0
6.25	1	6.2	3.7	4.7
6.50	1	2.5	1.5	2.5
6.75	1	1.0	1.0	2.0
7.0				
7.25				
7.50				
7.75				

TABLE 3.4
Seismic Source Parameters

Source 2 (Line)
Benioff & Costa Rica (40 - 79 km)

Time Data Base (T) : 73 years
Number of Recorded Events (N): 128
ν' from log-linear fit : 125
$\lambda'' = \lambda' + T = 73 + 73 = 146$
$\nu'' = \nu' + N = 125 + 128 = 254$
$\eta''_{M_i} = \eta'_{M_i} + N = 125 + 128 = 254$

Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit Fig. 3.8) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
4.0	26	125.0	20.0	46.0
4.24	9	105.0	19.0	28.0
4.50	22	86.0	15.0	37.0
4.75	6	71.0	12.0	18.0
5.0	10	59.0	11.0	21.0
5.25	7	48.0	7.0	14.0
5.50	10	41.0	7.0	17.0
5.75	5	34.0	5.5	10.5
6.0	13	28.5	5.0	18.0
6.25	3	23.5	4.0	7.0
6.50	3	19.5	3.5	6.5
6.75	7	16.0	2.5	9.5
7.0	3	13.5	5.9	8.9
7.25	4	7.6	6.6	10.6
7.50		1.0	1.0	1.0
7.75				

TABLE 3.5
Seismic Source Parameters

Source 3 (Line)
Benioff (80 - 109 km)

Time Data Base (T): 73 years
Number of Recorded Events (N): 51
ν' from log-linear fit: 50.5
$\lambda'' = \lambda' + T = 73 + 73 = 146$
$\nu'' = \nu' + N = 50.5 + 51 = 101.5$
$\eta''_{M_i} = \eta'_{M_i} + N = 50.5 + 51 = 101.5$

Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit Fig. 3.9) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
4.0	8	50.5	5.5	13.5
4.25	2	45.0	4.5	6.5
4.50	3	41.5	4.0	7.0
4.75	4	36.5	3.5	7.5
5.0	3	33.0	3.0	6.0
5.25	2	30.0	3.0	5.0
5.50	5	27.0	3.0	8.0
5.75	7	24.0	2.5	9.5
6.0	8	21.5	2.0	10.0
6.25	3	19.5	2.0	5.0
6.50	1	17.5	1.5	2.5
6.75	2	16.0	10.4	12.4
7.0	2	5.6	4.2	6.2
7.25	1	1.4	1.05	2.05
7.50		0.35	0.25	0.25
7.75		0.1	0.1	0.10

TABLE 3.6
Seismic Source Parameters

Source 4 (Line)
Benioff (110 - 159 km)

Time Data Base (T): 73 years
Number of Recorded Events (N): 16
ν' from log-linear fit: 18
$\lambda'' = \lambda' + T = 73 + 73 = 146$,
$\nu'' = \nu' + N = 18 + 16 = 34$
$\eta''_{M_i} = \eta'_{M_i} + N = 18 + 16 = 34$

Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit Fig. 3.10) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
4.0	5	18.0	2.7	7.7
4.25	1	15.3	2.3	3.3
4.50	1	13.0	2.0	3.0
4.75	0	11.0	1.5	1.5
5.0	1	9.5	1.5	2.5
5.25	0	8.0	1.2	1.2
5.50	1	6.8	1.1	2.1
5.75	1	5.7	0.8	1.8
6.0	2	4.9	0.8	2.8
6.25	0	4.1	0.6	0.6
6.50	2	3.5	0.5	2.5
6.75	1	3.0	2.6	2.6
7.0	1	1.4	0.95	1.95
7.25		0.45	0.35	0.35
7.50		0.1	0.1	0.1
7.75				

TABLE 3.7
Seismic Source Parameters

	Source 5 (Line) Benioff (160 - 215 km)
	Time Data Base (T) : 73 years Number of Recorded Events (N) : 31 ν' from log-linear fit : 31 $\lambda'' = \lambda' + T = 73 + 73 = 146$ $\nu'' = \nu' + N = 31 + 31 = 62$ $\eta''_{M_i} = \eta'_{M_i} + N = 31 + 31 = 62$

Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit Fig. 3.11) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
4.0	5	31.0	5.0	10.0
4.25	2	26.0	4.0	6.0
4.50	3	22.0	4.0	7.0
4.75	2	18.0	3.0	5.0
5.0	5	15.0	2.5	7.5
5.25	3	12.5	2.0	5.0
5.50	1	10.5	1.7	2.7
5.75	2	8.8	1.5	3.5
6.0	2	7.3	1.3	3.3
6.25	1	6.0	.9	1.9
6.50	0	5.1	.9	.9
6.75	2	4.2	.6	2.6
7.0	0	3.6	.6	.6
7.25	2	3.0	.5	2.5
7.50	0	2.5	.4	.4
7.75	1	2.1	1.2	2.2
8.0	0	.9	.58	.58
8.25	0	.32	.29	.29
8.50	0	.03	.03	.03
8.75				

TABLE 3.8
Seismic Source Parameters

	Source 6 (Line) Costa Rica (5 - 39 km)
	Time Data Base (T) : 73 years Number of Recorded Events (N) : 10 ν' from log-linear fit : 11 $\lambda'' = \lambda' + T = 73 + 73 = 146$ $\nu'' = \nu' + N = 11 + 10 = 21$ $\eta''_{M_i} = \eta'_{M_i} + N = 11 + 10 = 21$

Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit Fig. 3.12) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
4.0	1	11.0	2.0	3.0
4.25	2	9.0	1.6	3.6
4.50	2	7.4	1.4	3.4
4.75	1	6.0	1.0	2.0
5.0	1	5.0	.9	1.9
5.25	0	4.1	.7	.7
5.50	1	3.4	.6	1.6
5.75	0	2.8	.5	.5
6.0	0	2.3	.4	.4
6.25	0	1.9	.35	.35
6.50	2	1.55	1.3	3.3
6.75		.25	.15	.15
7.0		.1	.1	.1
7.25				
7.50				
7.75				

TABLE 3.9
Seismic Source Parameters

Source 7 (Line)
Atlantic (All depths)

Time Data Base (T) : 73 years
Number of Recorded Events (N): 7
ν' from log-linear fit: 7.75
$\lambda'' = \lambda' + T = 73 + 73 = 146$
$\nu'' = \nu' + N = 7.75 + 7 = 14.75$
$\eta''_{M_i} = \eta'_{M_i} + N = 7.75 + 7 = 14.75$

Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit Fig. 3.13) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
4.0	0	7.75	.6	.6
4.25	0	7.15	.6	.6
4.50	0	6.55	.5	.5
4.75	1	6.05	.5	1.5
5.0	2	5.55	.45	2.45
5.25	0	5.1	.4	.4
5.50	1	4.7	.4	1.4
5.75	0	4.3	.3	.3
6.0	1	4.0	.3	1.3
6.25	1	3.7	.4	1.4
6.50	0	3.3	1.9	1.9
6.75	0	1.4	.86	.86
7.0	1	.54	.32	1.32
7.25		.22	.12	.12
7.50		.1	.1	.1
7.75				

TABLE 3.10
Seismic Source Parameters

Source 8 (Line)
Pacific Coast Line (33 km)

Time Data Base (T): 73 years
Number of Recorded Events (N): 10
ν' from log-linear fit: 9.2
$\lambda'' = \lambda' + T = 73 + 73 = 146$
$\nu'' = \nu' + N = 9.2 + 10 = 19.2$
$\eta''_{M_i} = \eta'_{M_i} + N = 9.2 + 10 = 19.2$

Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit Fig. 3.14) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
4.0	1	9.2	.8	1.8
4.25	1	8.4	.7	1.7
4.50	1	7.7	.7	1.7
4.75	1	7.0	.6	1.6
5.0	4	6.4	.6	4.6
5.25	0	5.8	.5	.5
5.50	1	5.3	.5	1.5
5.75	0	4.8	.4	.4
6.0	0	4.4	.4	.4
6.25	1	4.0	3.1	4.1
6.50		.9	.8	.8
6.75		.1	.1	.1
7.0				
7.25				
7.50				
7.75				

TABLE 3.11
Seismic Source Parameters

	Sources 9 & 10 (Lines) Line of Volcanoes (33 km)			
	Time Data Base (T): 123 years Number of Recorded Events (N): 54 ν' from log-linear fit: 54 $\lambda'' = \lambda' + T = 123 + 123 = 246$ $\nu'' = \nu' + N = 54 + 54 = 108$ (for both sources together); $\nu'' = 108/2 = 54$ for each source. $\eta''_{M_i} = \eta'_{M_i} + N = 54 + 54 = 108$			
Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit Fig. 3.15) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
4.0	1	54.0	3.0	4.0
4.25	0	51.0	3.0	3.0
4.50	2	48.0	3.0	5.0
4.75	1	45.0	2.5	3.5
5.0	1	42.5	2.5	3.5
5.25	2	40.0	2.4	4.4
5.50	11	37.6	2.1	13.1
5.75	13	35.5	2.0	15.0
6.0	7	33.5	2.0	9.0
6.25	2	31.5	2.0	4.0
6.50	5	29.5	9.5	14.5
6.75	5	20.0	14.8	19.8
7.0	3	5.2	3.7	6.7
7.25	1	1.5	1.05	2.05
7.50		.45	.35	.35
7.75		.1	.1	.1

TABLE 3.12
Seismic Source Parameters

	Source 11 (Area) Managua Area (5 km)			
	Time Data Base (T): 73 years Number of Recorded Events (N): 5 ν' from log-linear fit : 6.5 $\lambda'' = \lambda' + T = 73 + 73 = 146$ $\nu'' = \nu' + N = 6.5 + 5 = 11.5$ $\eta''_{M_i} = \eta'_{M_i} + N = 6.5 + 5 = 11.5$			
Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit Fig. 3.16) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
4.0	1	6.5	1.1	2.1
4.25	0	5.4	.9	.9
4.50	0	4.5	.8	.8
4.75	1	3.7	.6	1.6
5.0	1	3.1	.5	1.5
5.25	0	2.6	.48	.48
5.50	1	2.12	.37	1.37
5.75	0	1.75	.27	.27
6.0	0	1.48	.27	.27
6.25	1	1.21	.41	1.41
6.50		.8	.8	.8
6.75				
7.0				
7.25				
7.50				
7.75				

TABLE 3.13

Seismic Source Parameters

Source 12 (Area)
Gulf of Fonseca (33 km)

Time Data Base (T) : 73 years
Number of Recorded Events (N) : 7
ν' from log-linear fit : 7.7
$\lambda'' = \lambda' + T = 73 + 73 = 146$
$\nu'' = \nu' + N = 7.7 + 7 = 14.7$
$\eta''_{M_i} = \eta'_{M_i} + N = 7.7 + 7 = 14.7$

Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit Fig. 3.17) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
4.0	0	7.70	.15	.15
4.25	0	7.55	.15	.15
4.50	0	7.4	.1	.1
4.75	0	7.3	.1	.1
5.0	0	7.2	.1	.1
5.25	0	7.1	.1	.1
5.50	4	7.0	.1	4.1
5.75	1	6.9	.1	1.1
6.0	1	6.8	4.8	5.8
6.25	1	2.0	1.9	2.9
6.50		.1	.1	.1
6.75				
7.0				
7.25				
7.50				
7.75				

TABLE 3.14

Seismic Source Parameters

Source 13 (Area)
Costa Rica Area (80 - 109 km)

Time Data Base (T): 73 Years
Number of Recorded Events (N): 4
ν' from log-linear fit: 5.4
$\lambda'' = \lambda' + T = 73 + 73 = 146$
$\nu'' = \nu' + N = 5.4 + 4 = 9.4$
$\eta''_{M_i} = \eta'_{M_i} + N = 5.4 + 4 = 9.4$

Richter Magnitude (M_i)	Nb of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative Nb of Occurrences (log-linear fit Fig. 3.18) (N_c)	Nb of Occurrences in M_i bands (log-linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
4.0	1	5.4	.8	1.8
4.25	0	4.6	.6	.6
4.50	1	4.0	.5	1.5
4.75	0	3.5	.5	.5
5.0	0	3.0	.4	.4
5.25	0	2.6	.4	.4
5.50	1	2.2	.3	1.3
5.75	0	1.9	.25	.25
6.0	0	1.65	.25	.25
6.25	0	1.4	.2	.2
6.50	0	1.2	.15	.15
6.75	0	1.05	.15	.15
7.0	1	.9	.5	1.5
7.25		.4	.3	.3
7.50		.1	.1	.1
7.75				

Poisson Model

The generating process for the number of occurrences is the Poisson model with uncertain mean rate of occurrence λ (eq. 2.1). The parameter λ is treated as a random variable and Bayesian statistics is applied to it.

The sample likelihood function on λ (eq. 2.4) is derived from the generating Poisson model. The parameters T and N of the sample likelihood function are determined from the available data. T represents the time base for which the data is available: 73 years for all sources except for the two volcano lines for which it is 123 years. N represents the total number of occurrences observed on the source considered during this time period.

The gamma prior distribution on λ (eq. 2.3) is based on the subjective input of the analyst. The numerical values of the parameters λ' and ν' are obtained from this subjective input. For this study, it is assumed that the values of λ' and ν' are respectively equal to T and N of the corresponding source. The implication of this assumption is that the subjective information of the expert is similar to the available data. In other words, the analyst has as much confidence in his subjective input as he has in the data.

Based on the values of λ', ν', T and N, the parameters λ'' and ν'' of the posterior distribution on λ (eq. 2.7) can be calculated for each source. It should be pointed out that in the absence of any subjective information (diffuse prior), the analysis can be carried out with objective data alone and in the absence of any objective data, the analysis can be carried out with subjective information alone. Knowledge of λ'' and ν'' completely defines -- in a posterior sense -- the probability function for the mean rate of occurrence λ for the source considered during a future time t.

Convolving the conditional Poisson generating process for the number of occurrences with the posterior distribution on λ, the marginal distribution for the number of occurrences (eq. 2.9) is derived for each source considered. This distribution does not give any information on the magnitude of the occurrences. The next step is to obtain the posterior conditional distribution on magnitudes.

Bernoulli Trials

The generating process for the number r_{M_i} of events of any specific M_i given that a total of n events have occurred is the binomial model. However, the probability of success p_{M_i} for each trial has been assumed to be uncertain. The parameter p_{M_i} is treated as a random variable and Bayesian statistics is applied to it.

The sample likelihood function on p_{M_i} (eq. 2.15) is derived from the generating binomial process. From the available data, the parameters N and R_{M_i} of the sample likelihood function can be determined. N represents the total number of events recorded on the source under consideration and R_{M_i} represents the number of earthquakes of magnitude M_i (successes) recorded on the same source. R_{M_i} must be determined for each source and each M_i.

Using the conjugate beta prior (eq. 2.13) for the distribution on p_{M_i}, the parameters η'_{M_i} and ξ'_{M_i} are determined from the analyst's subjective input. For this case study, it is assumed that the analytical recurrence relationship fitted to the data for each source constitutes the subjective input. For each individual source, the analytical relationship describing the recurrence of various M_i events is given by the following log-linear relationship

$$\ln \ N(M) = \alpha + \beta M$$

where $N(M)$ = Number of events above magnitude M

M = Richter magnitude

α and β are regression constants.

Figures 3.7 through 3.18 (Figures 3.2 through 3.13 from Shah, et al., 1975) show these recurrence relationships for all the seismic sources considered. Table 3.15 gives the summary of α and β values for each source and the cutoff point corresponding to $\ln N(M) = 0.1$. It can be seen from Table 3.15 as well as from Figures 3.7 through 3.18 that most of the analytical recurrence relationships fitted to the data are bilinear.

The prior η'_{M_i} represents the subjective knowledge about the number of events for a source above the fixed lower bound ($M_i = 4.0$). As an example, consider the source 1. From Figure 3.7 the η'_{M_i} corresponding to this source is 72. ξ'_{M_i} represents the number of earthquakes of magnitude M_i. Again from Figure 3.7, for $M = 3.875$, $Nc = 72$ and for $M = 4.125$, $Nc = 54$ thus, for $M_i = 4.0$, ξ'_{M_i} is equal to $72 - 54 = 18$. Because of the definition of the prior, within each source, η'_{M_i} is constant for

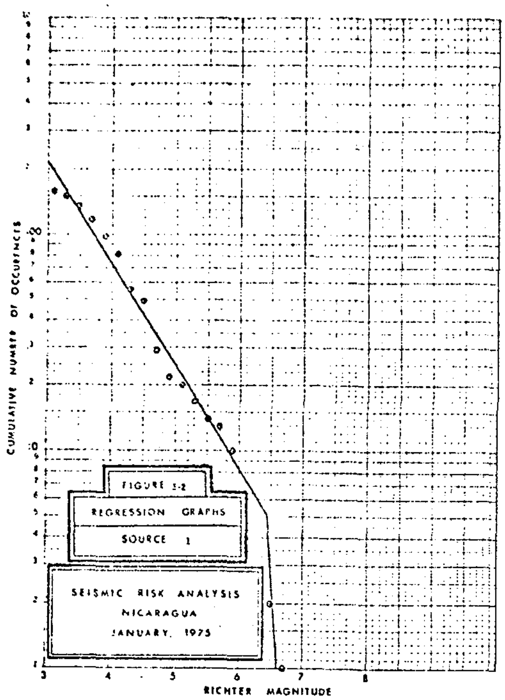


FIGURE 3.7

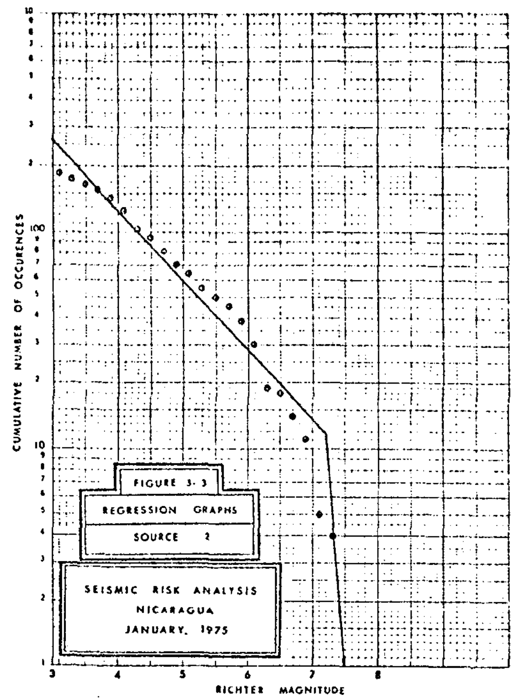


FIGURE 3.8

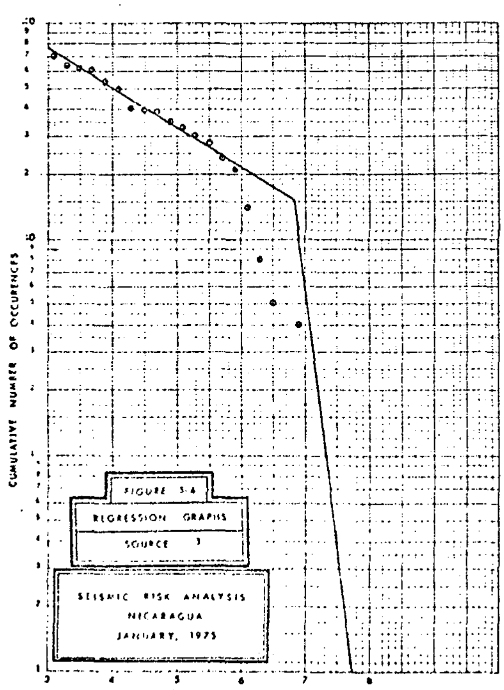


FIGURE 3.9

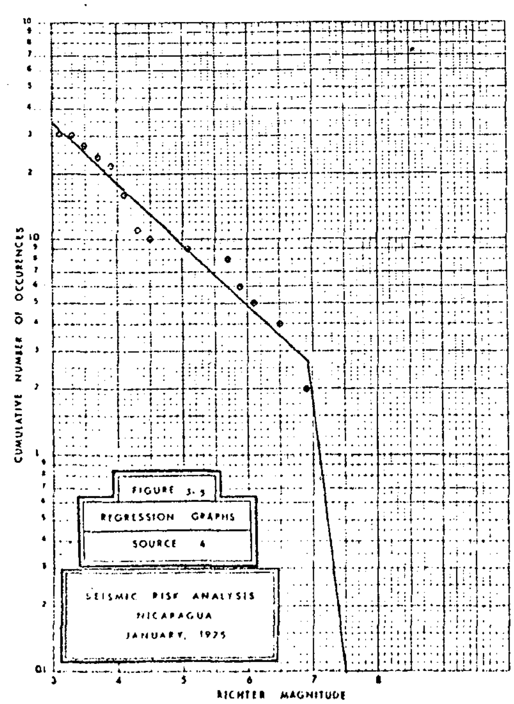


FIGURE 3.10

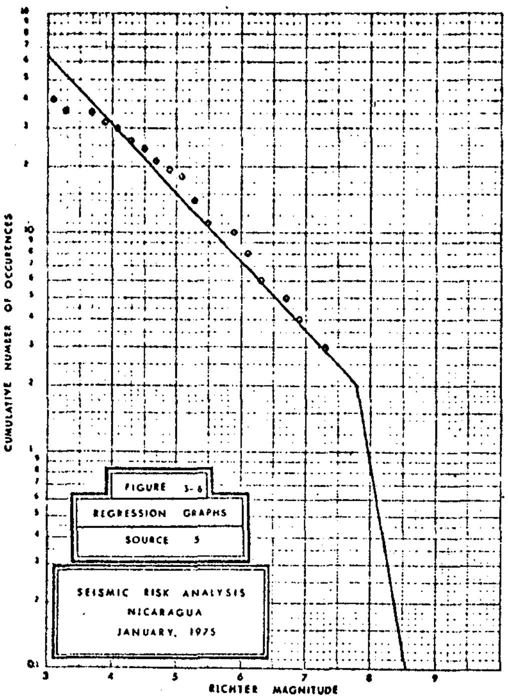


FIGURE 3.11

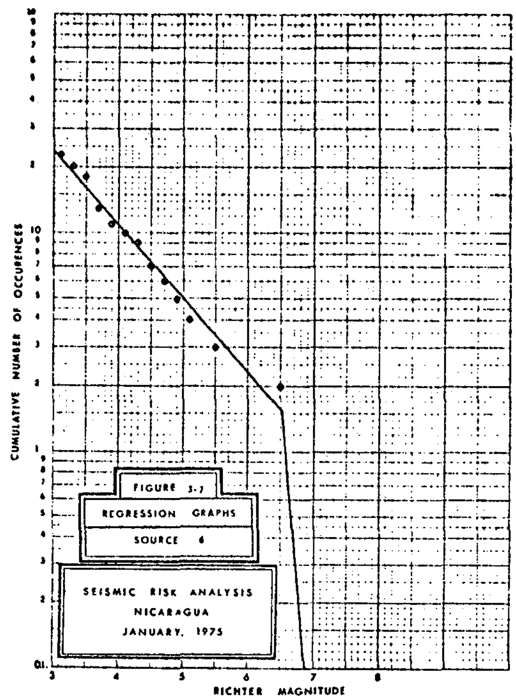


FIGURE 3.12

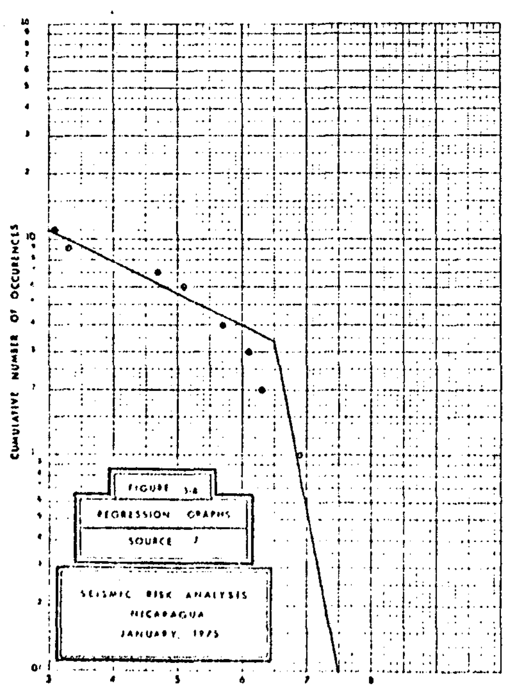


FIGURE 3.13

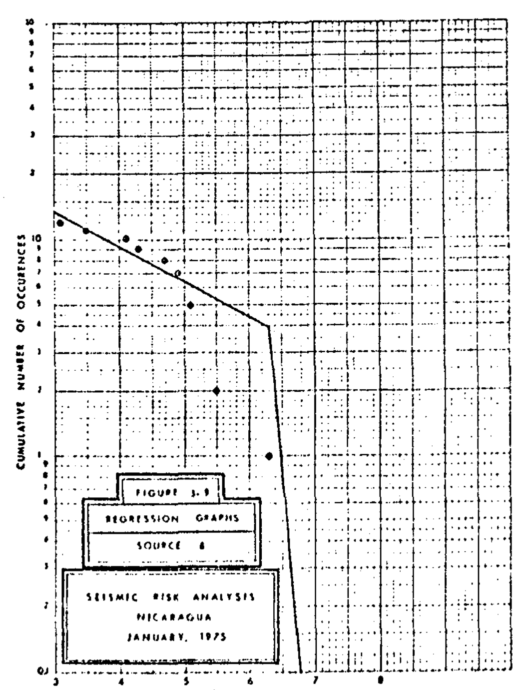


FIGURE 3.14

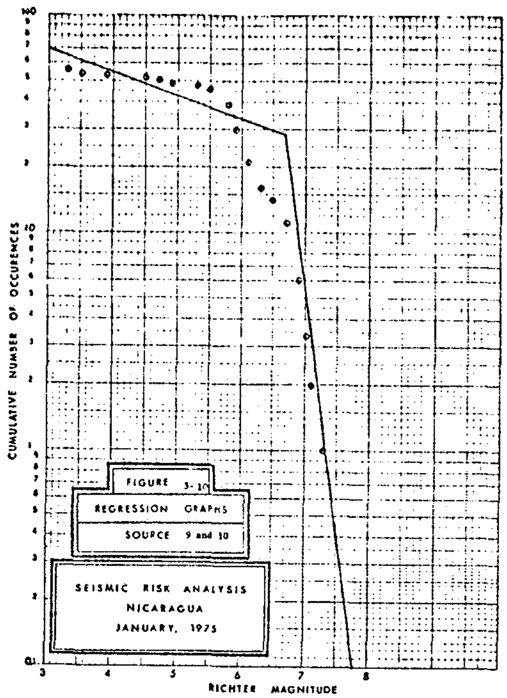


FIGURE 3.15

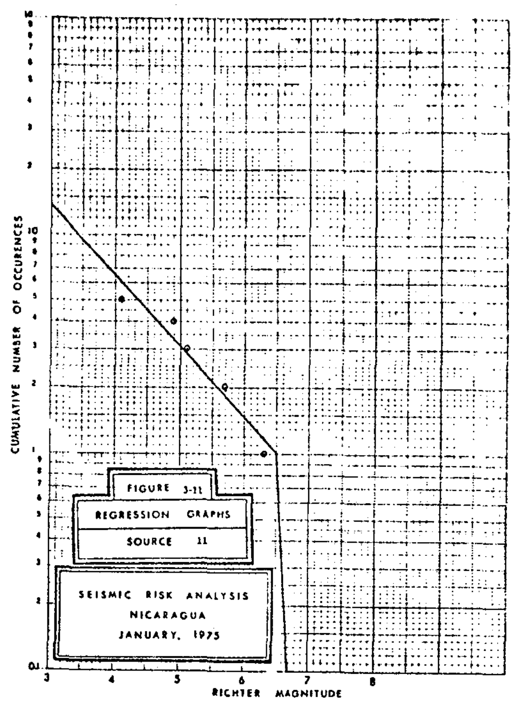


FIGURE 3.16

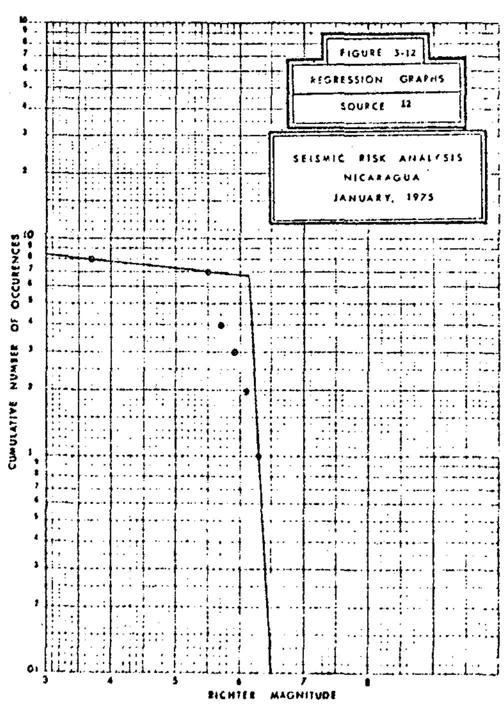


FIGURE 3.17

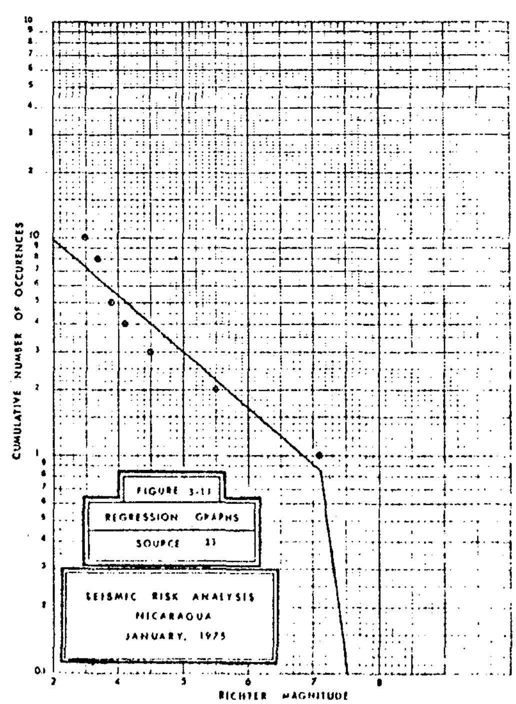


FIGURE 3.18

all M_i's. If the prior had been input differently such as in the form of a distribution for each M_i, different η'_{M_i} could have been obtained. The condition

$$\sum_{\text{all } M_i} \frac{\xi'_{M_i}}{\eta'_{M_i}} = 1.0 \qquad \text{(2.14 repeated)}$$

obviously satisfied in this case, should then have been checked and satisfied by normalizing these ratios.

Having determined the parameters of the sample likelihood function as well as the ones of the prior distribution, the posterior parameters η''_{M_i} and ξ''_{M_i} (eq. 2.18) can be obtained by using the concept of conjugate distribution. The knowledge of η''_{M_i} and ξ''_{M_i} completely defines -- in the posterior sense -- the probability distribution of the probability of success p_{M_i} of magnitude M_i on the source considered.

The marginal distribution on the number of successes M_i's (eq. 2.20) is obtained by convolving the posterior distribution on p_{M_i} and the conditional generating process of r_{M_i}. However, this marginal distribution is still conditional on the number of events n.

Combining the distribution of r_{M_i} for given n (eq. 2.20), with the distribution on n (eq. 2.9) gives the marginal Bayesian distribution on r_{M_i} (eq. 2.21). This information completes the description of seismicity for a given source.

To obtain the probabilistic information on the peak ground acceleration and duration at the site, the above information on the

Table 3.15

Parameters of Recurrence Relationships

Source	α_1	β_1	α_2	β_2	Cutoff
1.	8.66	-1.09	30.06	-4.55	6.8
2.	7.78	-0.74	69.08	-9.21	7.8
3.	5.59	-0.42	42.02	-5.75	7.7
4.	5.49	-0.65	32.34	-4.55	7.5
5.	6.31	-0.72	42.16	-5.27	8.5
6.	5.47	-0.77	51.55	-7.82	6.9
7.	3.40	-0.33	24.15	-3.53	7.5
8.	3.73	-0.37	47.68	-7.57	6.8
9.	4.99	-0.24	39.65	-5.43	7.8
10.	4.99	-0.24	39.65	-5.43	7.8
11.	4.81	-0.74	80.79	-12.40	6.7
12.	2.35	-0.07	82.15	-13.04	6.5
13.	4.05	-0.59	39.27	-5.54	7.5

seismicity of various sources must be combined with the attenuation relationships presented in Chapter II.

As mentioned in that chapter, a uniform distribution with a constant coefficient of variation is used to describe the scatter of the attenuation data with respect to the mean.

Figure 3.19 shows the cumulative distribution function for the peak ground acceleration for Managua. The future time period considered is 50 years. The assumed coefficients of variation on the attenuation relationship are 0.0, 0.3 and 0.5. The dotted line indicates the results from a previous study (Shah, et al., 1975).

Figure 3.20 shows the cumulative distribution function for the duration for Managua. The time period considered is 50 years. The assumed coefficients of variation on the attentuation relationship are 0.0, 0.3 and 0.5. No similar results are available in the literature for comparison.

Comparing the cumulative distribution function from this study with the one obtained in Shah, et al., (1975)(Figure 3.19), the following observations can be made.

- With a zero coefficient of variation, the Bayesian approach leads to smaller accelerations. This can be explained by the following: the combination of the Poisson-gamma and binomial-beta models produces smaller probabilities than the Poisson model only. This is noticed in simple test runs in which the data is as similar as the difference in input format permits. Moreover, the data used in the Bayesian approach is less conservative than the one used in the

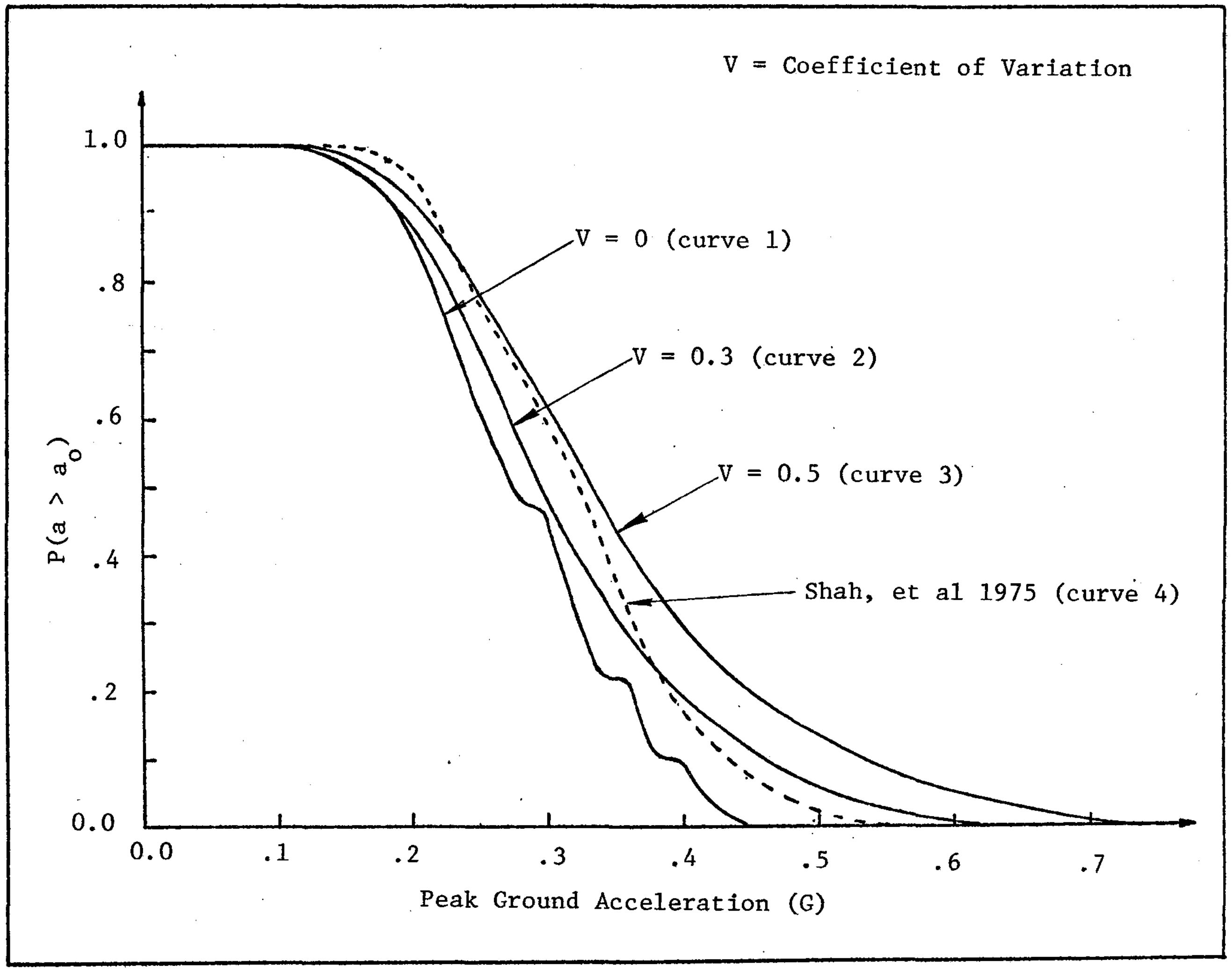


FIGURE 3.19. Probability of Peak Ground Acceleration $P(a>a_o)$

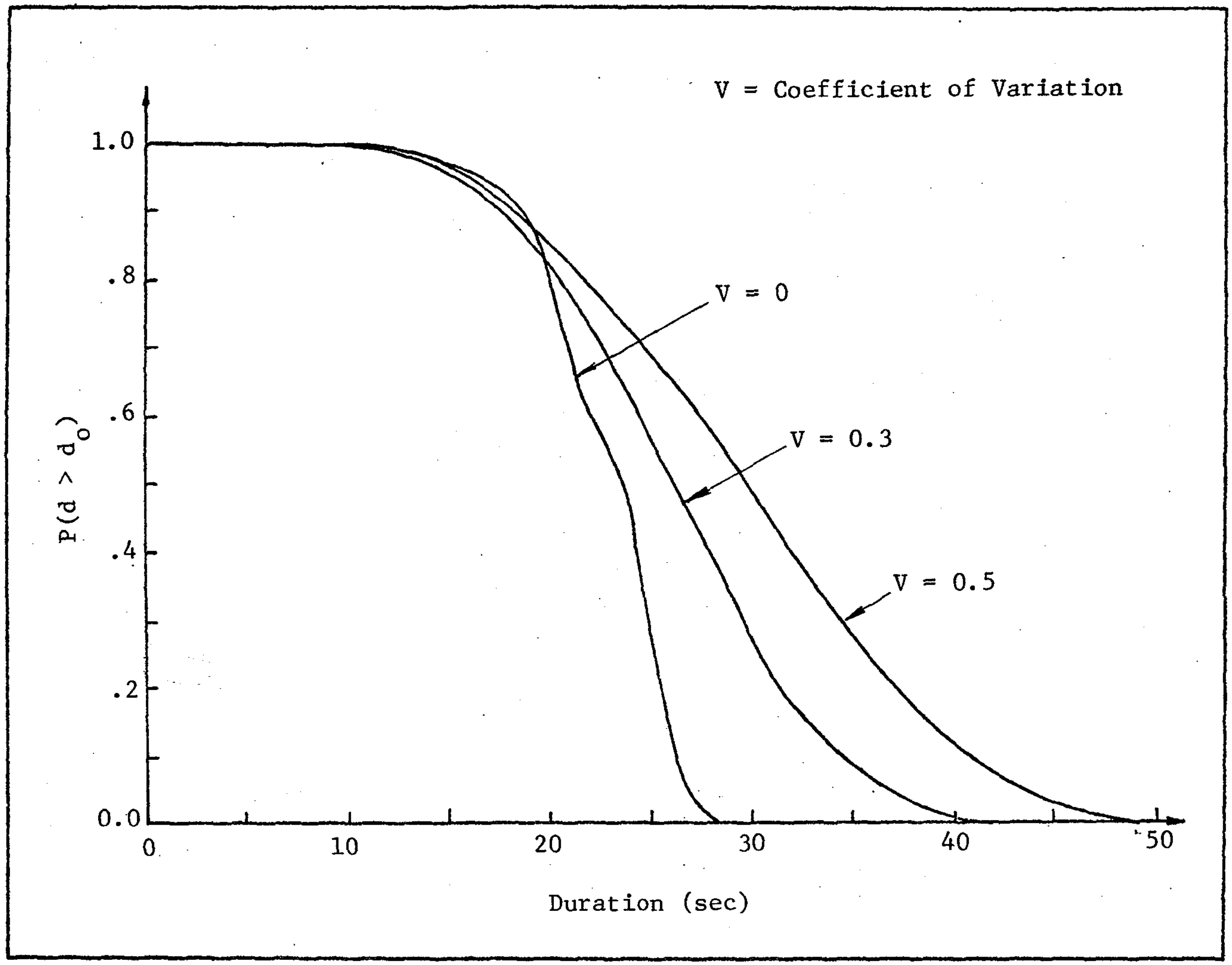


FIGURE 3.20. Probability of Duration $P(d>d_o)$

Poisson model. The log-linear recurrence relationships are the sole data to the Poisson model. In the present model the log-linear recurrences are combined with the available data through Bayesian statistics. This introduces a decrease in seismicity as explained below. For large M's where insufficient information is available to obtain a good fit, it is common to adopt a conservative approach. Hence for those magnitudes, that are governing the results, the log-linear recurrence relationship often implies a seismicity greater than the one shown by the data itself. (Figures 3.7 through 3.18). Therefore the combination of the data and the log-linear fit results in seismicity smaller than the one described by the recurrence relationships only.

- Curve 1 is not as smooth as curve 4. Both models are very sensitive to the value of the upper cutoff on each source. In the present model it is input as an abrupt cutoff, whereas in the Poisson model it is input as a sharp but continuous decrease which for small probabilities extends beyond the cutoff value. Therefore the switch of the governing influence from one source to another as the PGA increases does not appear as sharply. This produces a smoother CDF. Moreover, the treatment of the acceleration as a discrete variable (curve 1) must of necessity introduce some round off approximations.
- Increasing the coefficient of variation of the attenuation relationship increases the probability of exceeding a given level of peak ground acceleration. This is expected. A coefficient of variation

of zero implies that the attenuation relationship has no scatter. As the coefficient of variation increases, the uncertainty associated with the attenuation relationship increases. This results in larger accelerations for the same M and distance.

- The probability of exceeding a given PGA approaches the results presented in Shah, et al. (1975) (Curve 4) as the coefficient of variation increases from 0.0 to 0.3. The versatility of the present model and its superiority over the currently available models is obvious.
- Similar behavior regarding duration is observed in Figure 3.20 as the coefficient of variation in duration attenuation increases, the probability of exceedence for a given duration also increases. No comparison can be made about this behavior since similar results are not available in the literature.

Figures 3.21 and 3.22 emphasize the behavior of the PGA and duration as a function of the coefficient of variation in PGA and duration attenuations: larger uncertainty in the attenuation relationships results in higher values of PGA or duration.

In developing some iso-acceleration maps for Nicaragua, the following cases are considered.

1. Economic life of 30 years. 10% chance of exceedence. Coefficients of variation of 0.0 and 0.3.
2. Economic life of 50 years. 10% chance of exceedence. Coefficients of variation of 0.0 and 0.3.

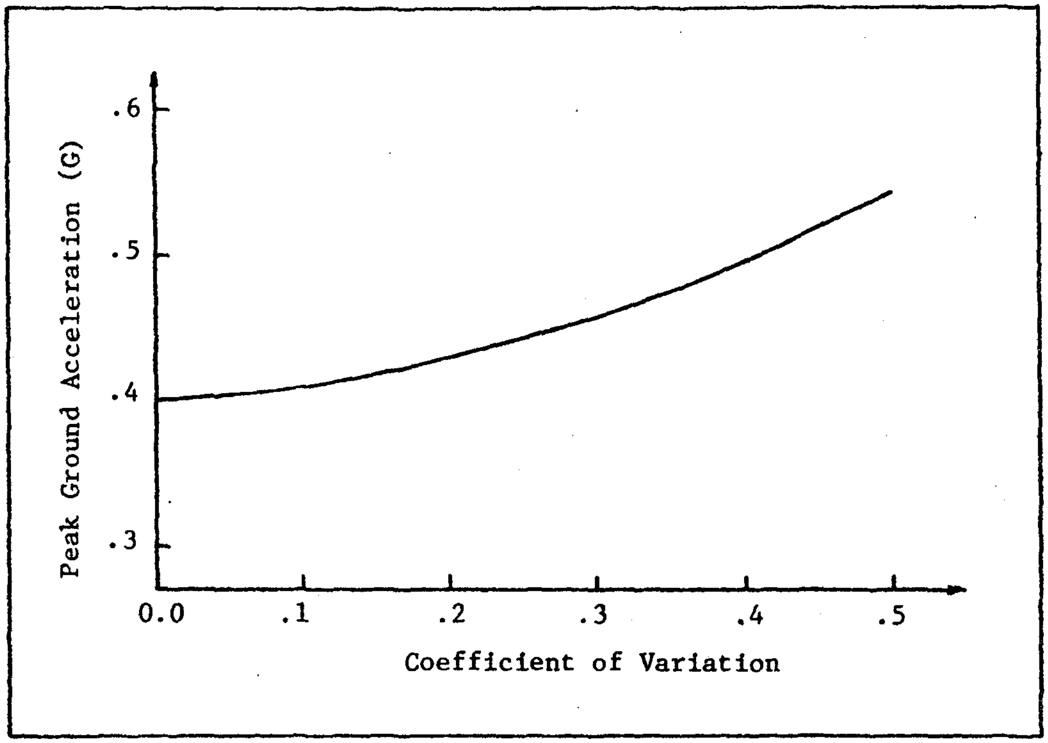


FIGURE 3.21. Peak Ground Acceleration $P(a>a_o) = 0.10$

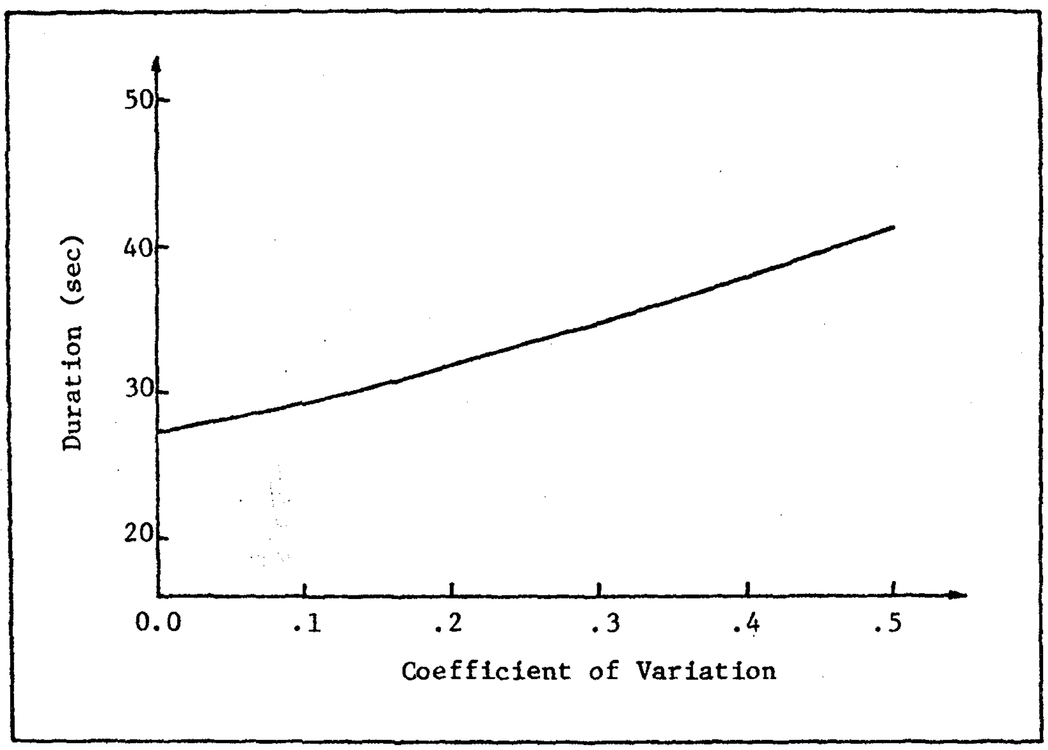


FIGURE 3.22. Duration $P(d>d_o) = 0.10$

Thus four iso-acceleration maps (Fig. 3.23 through 3.26) and four iso-duration maps (Fig. 3.27 through 3.30) are developed. The maps are drawn for return periods corresponding to 475 years. Comparing the iso-acceleration map of this study having a coefficient of variation of 0.3 and 475 years return period with the map developed in Shah, et al., (1975). The following comments can be made.

- For the same data base, the shapes of the iso-acceleration lines are very similar.
- The peak ground accelerations obtained from this study (for a coefficient of variation of 0.3) are slightly smaller.
- The iso-duration maps developed here are unique and no comparable results are available in the literature. However the values presented here look reasonable and in good agreement with past events.
- For a given region and a given return period the peak increases with the increase in coefficient of variation of the attenuation relationship.

3.4 Conclusions

In this chapter, a method of using the available data and the subjective information to obtain seismic hazard for a region is presented. It is shown that any geological information, no matter how subjective, can be incorporated in describing the seismicity of a fault or a source. Once such an information is incorporated in the hazard mapping methodology, any objection to the use of historical data alone can be removed. The purpose of presenting the Nicaragua seismic hazard map is not only to explain the Bayesian methodology but

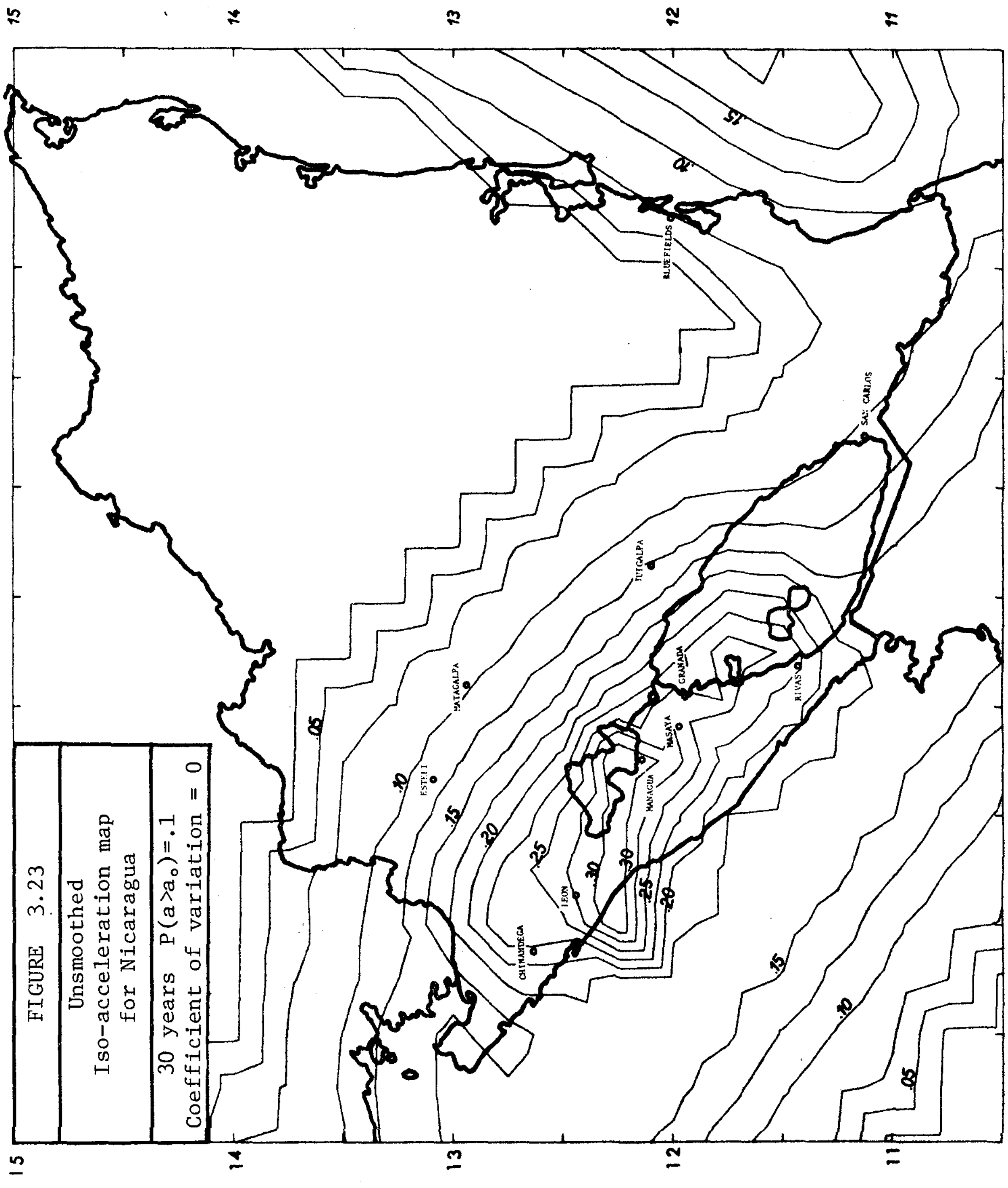


FIGURE 3.23

Unsmoothed Iso-acceleration map for Nicaragua

30 years $P(a>a_o)=.1$
Coefficient of variation = 0

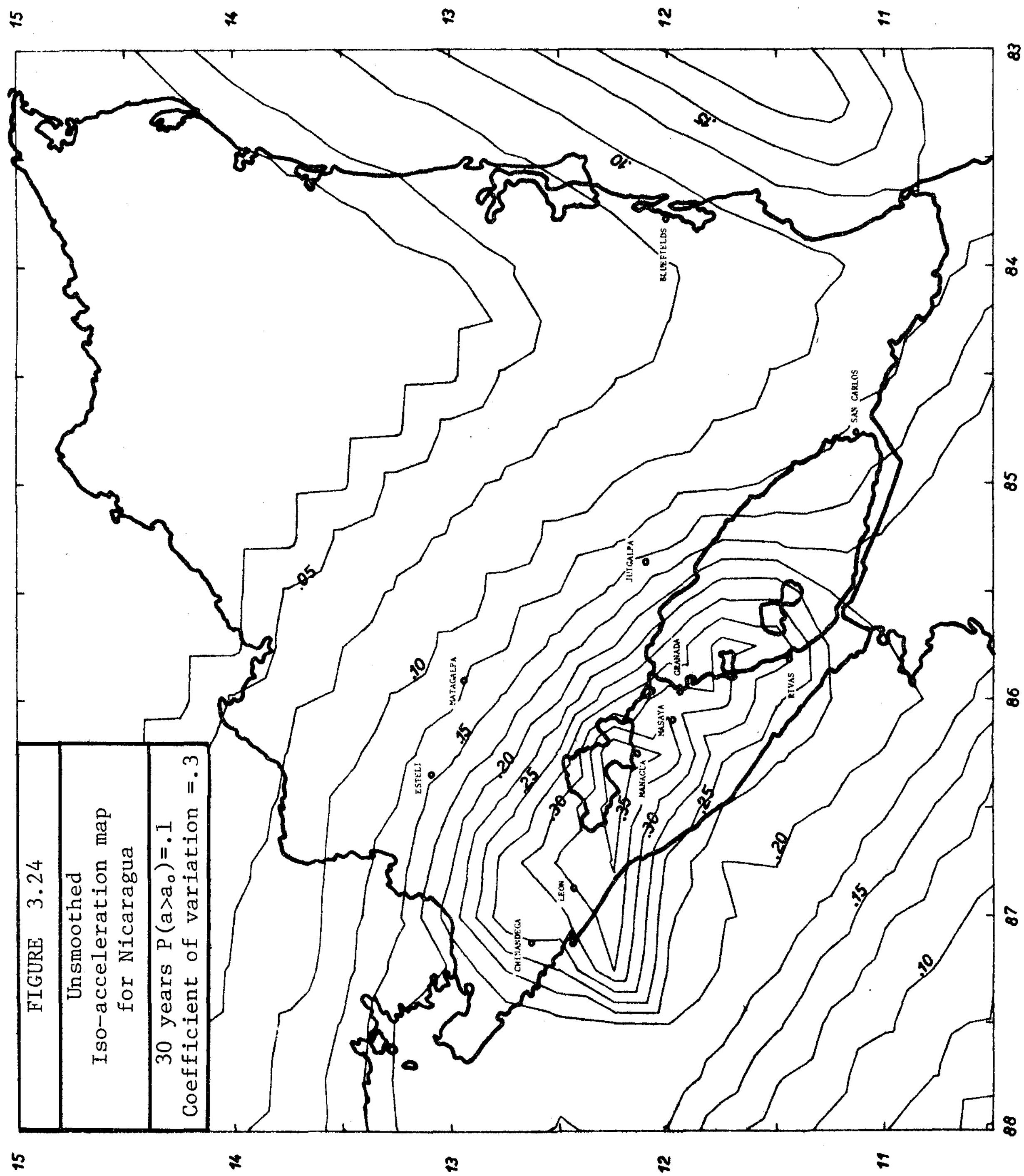


FIGURE 3.24

Unsmoothed
Iso-acceleration map
for Nicaragua

30 years $P(a>a_o)=.1$
Coefficient of variation $=.3$

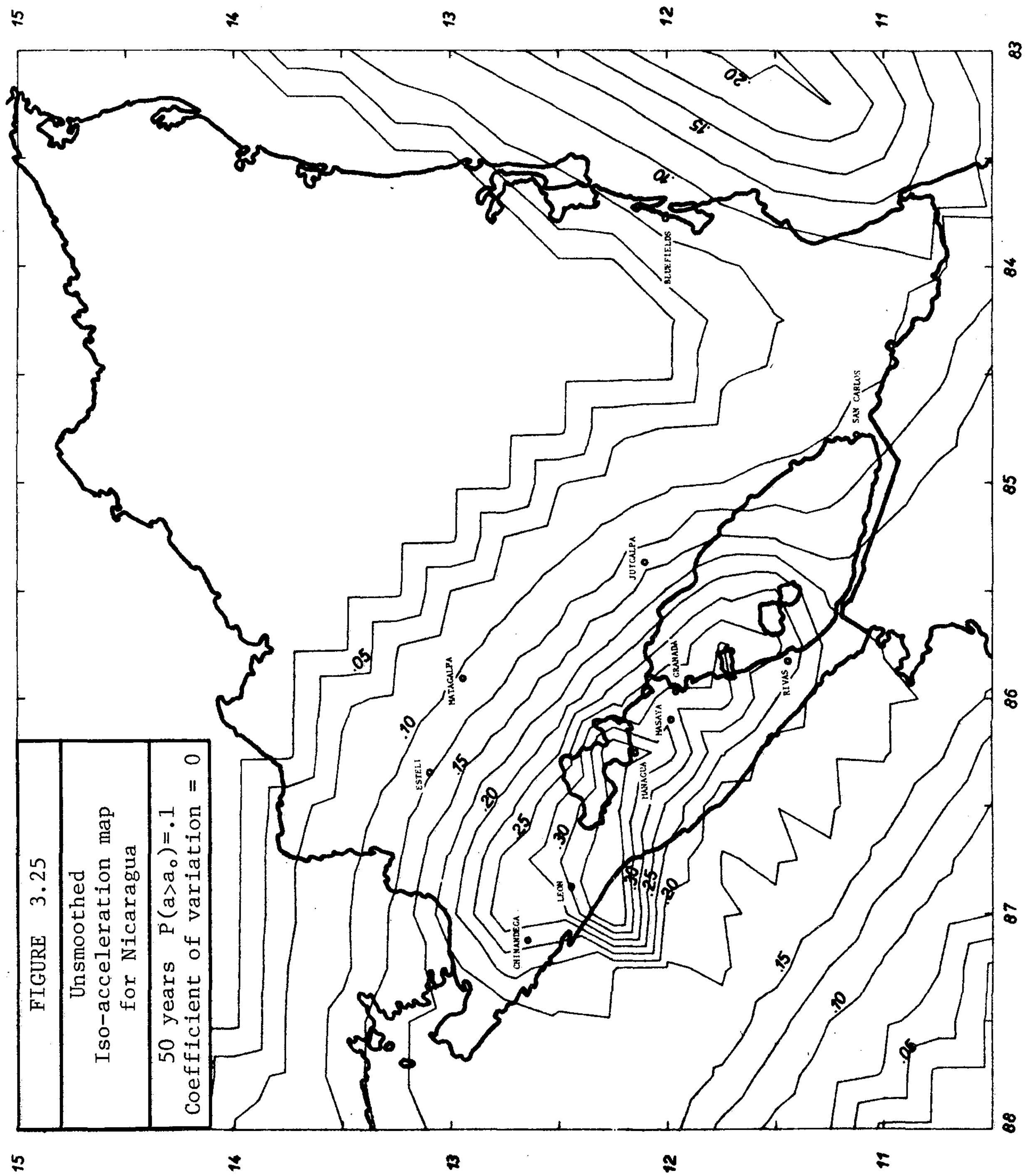


FIGURE 3.25

Unsmoothed Iso-acceleration map for Nicaragua

50 years $P(a>a_o)=.1$
Coefficient of variation = 0

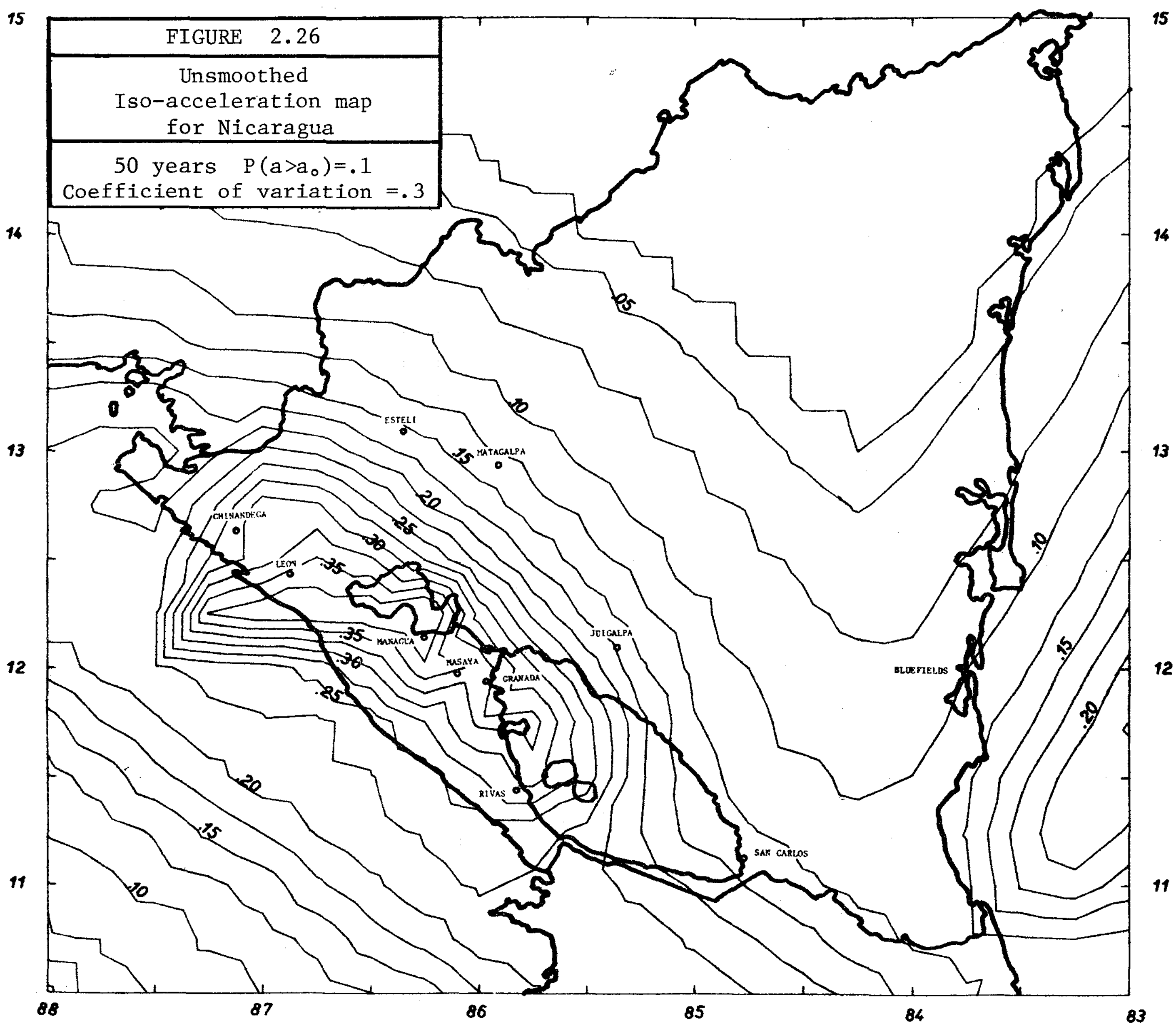


FIGURE 2.26

Unsmoothed
Iso-acceleration map
for Nicaragua

50 years $P(a>a_o)=.1$
Coefficient of variation =.3

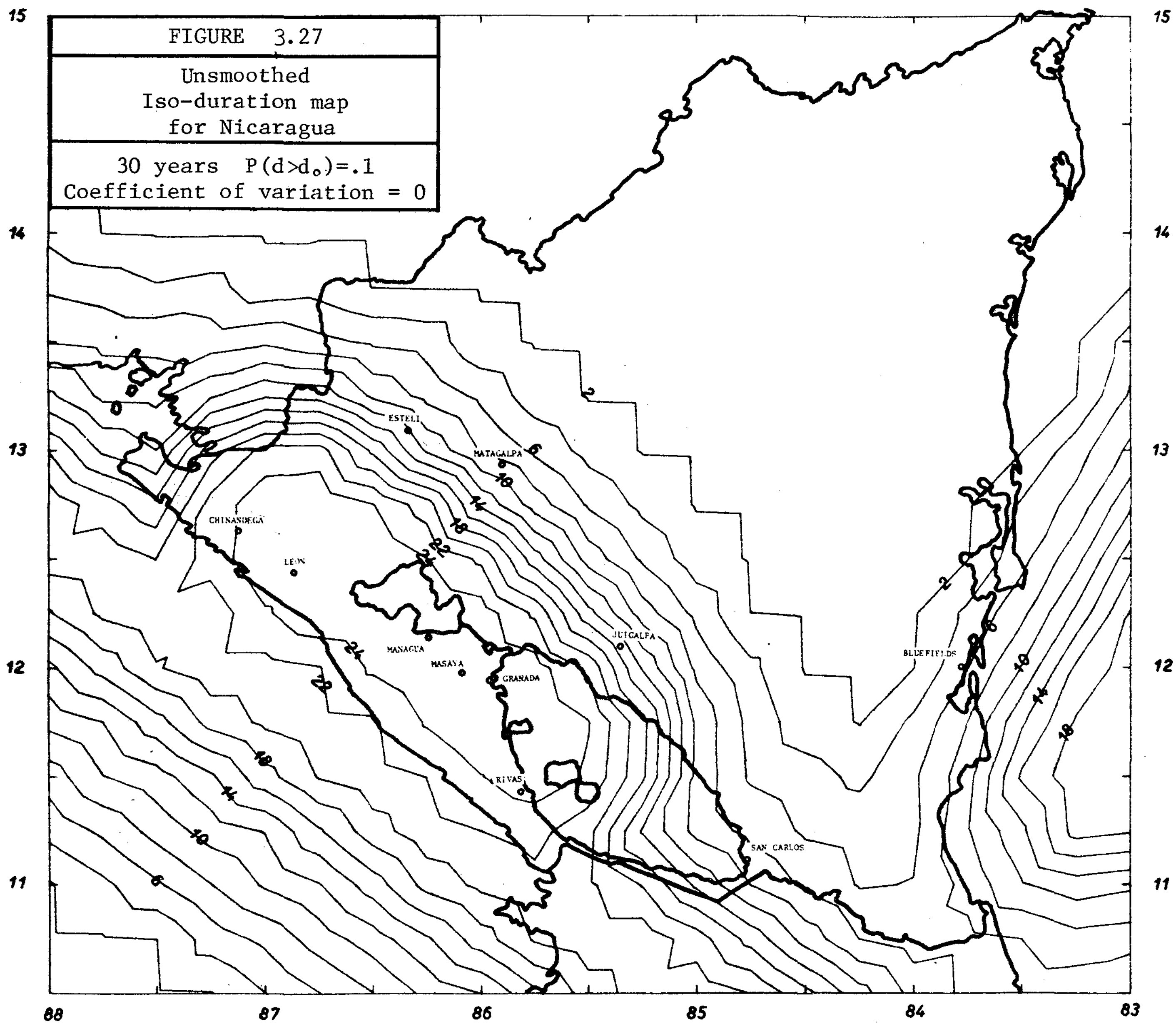


FIGURE 3.27

Unsmoothed Iso-duration map for Nicaragua

30 years $P(d>d_o)=.1$
Coefficient of variation = 0

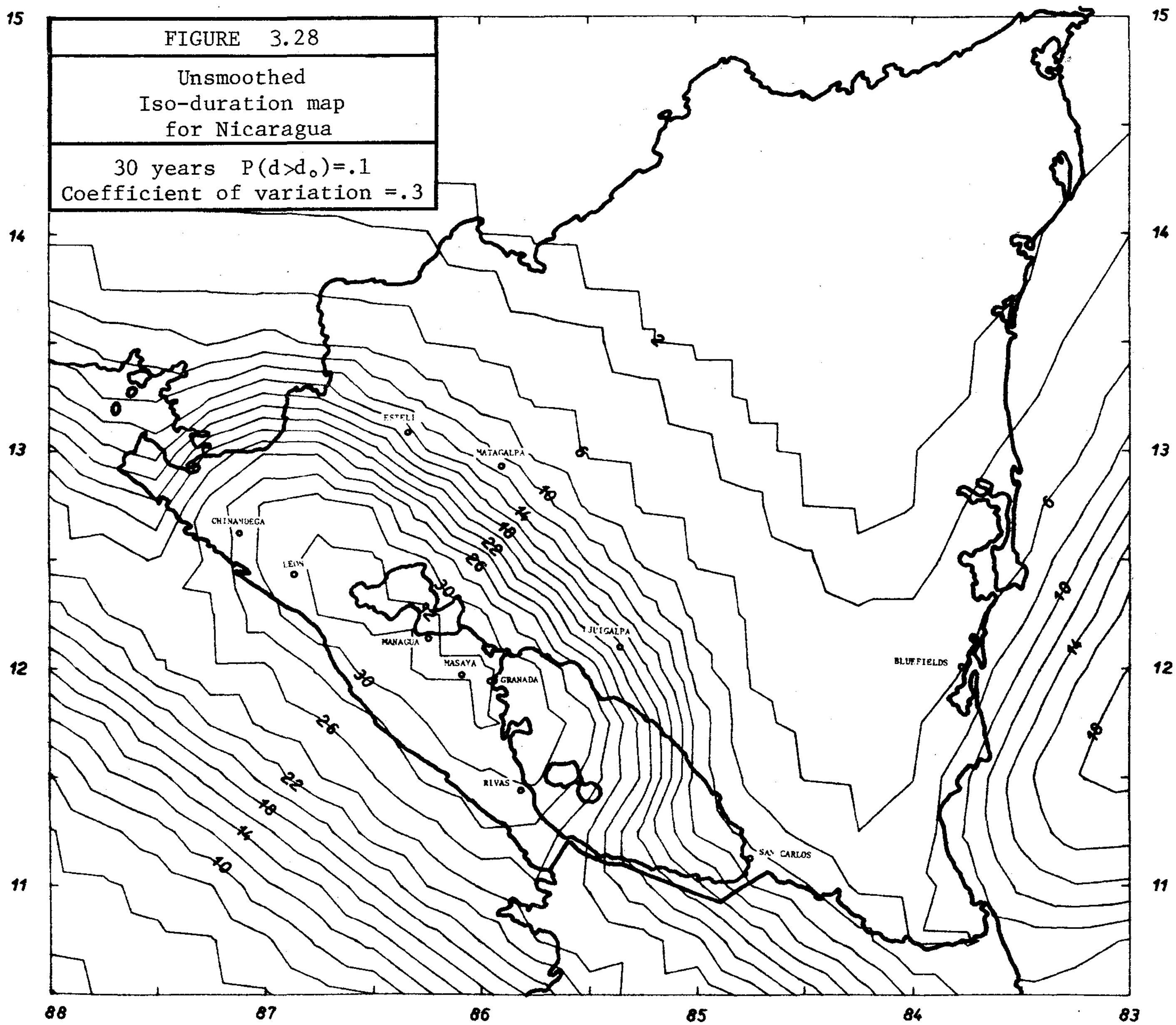


FIGURE 3.28

Unsmoothed Iso-duration map for Nicaragua

30 years $P(d>d_o)=.1$
Coefficient of variation =.3

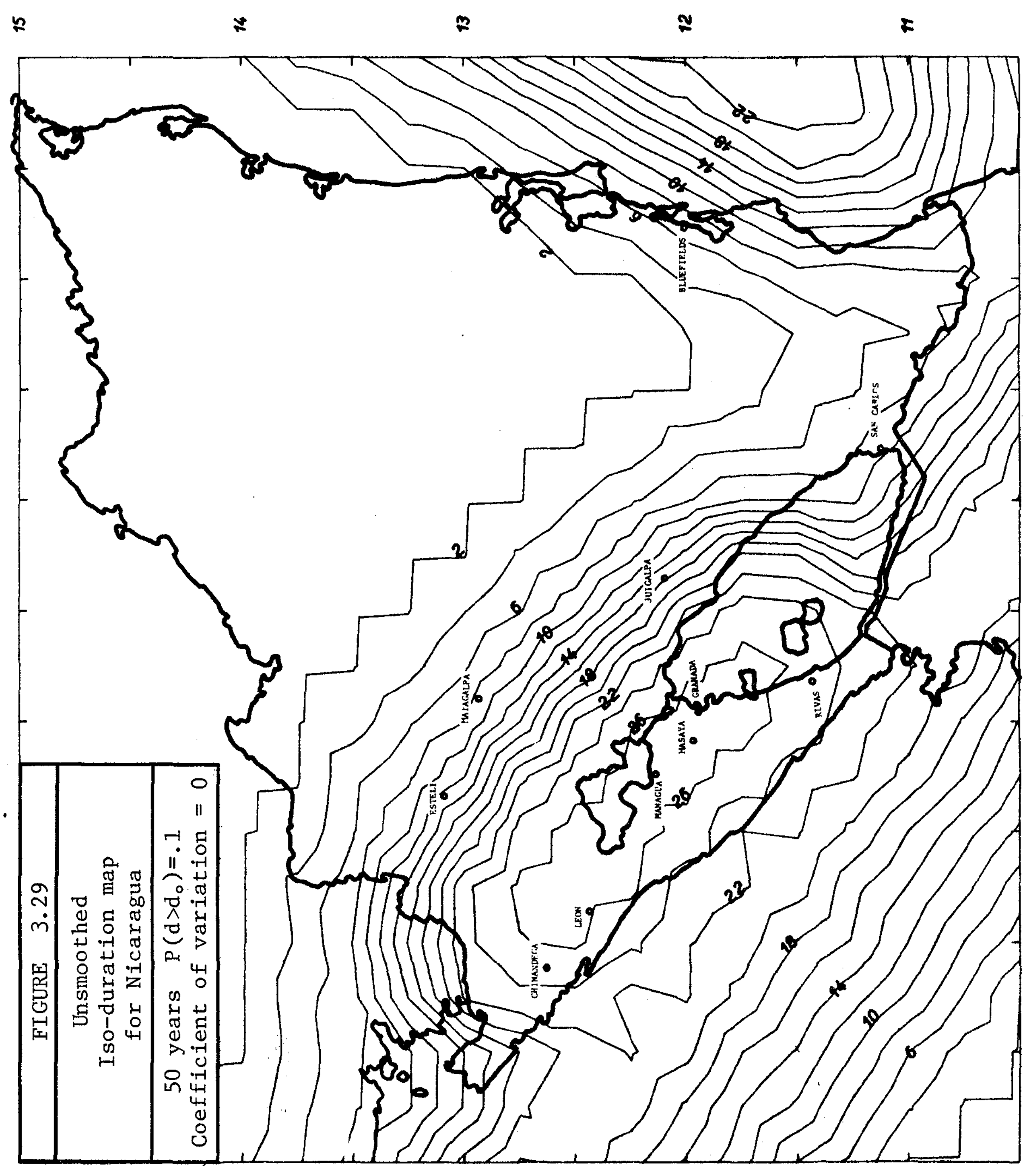


FIGURE 3.29

Unsmoothed
Iso-duration map
for Nicaragua

50 years $P(d>d_o)=.1$
Coefficient of variation = 0

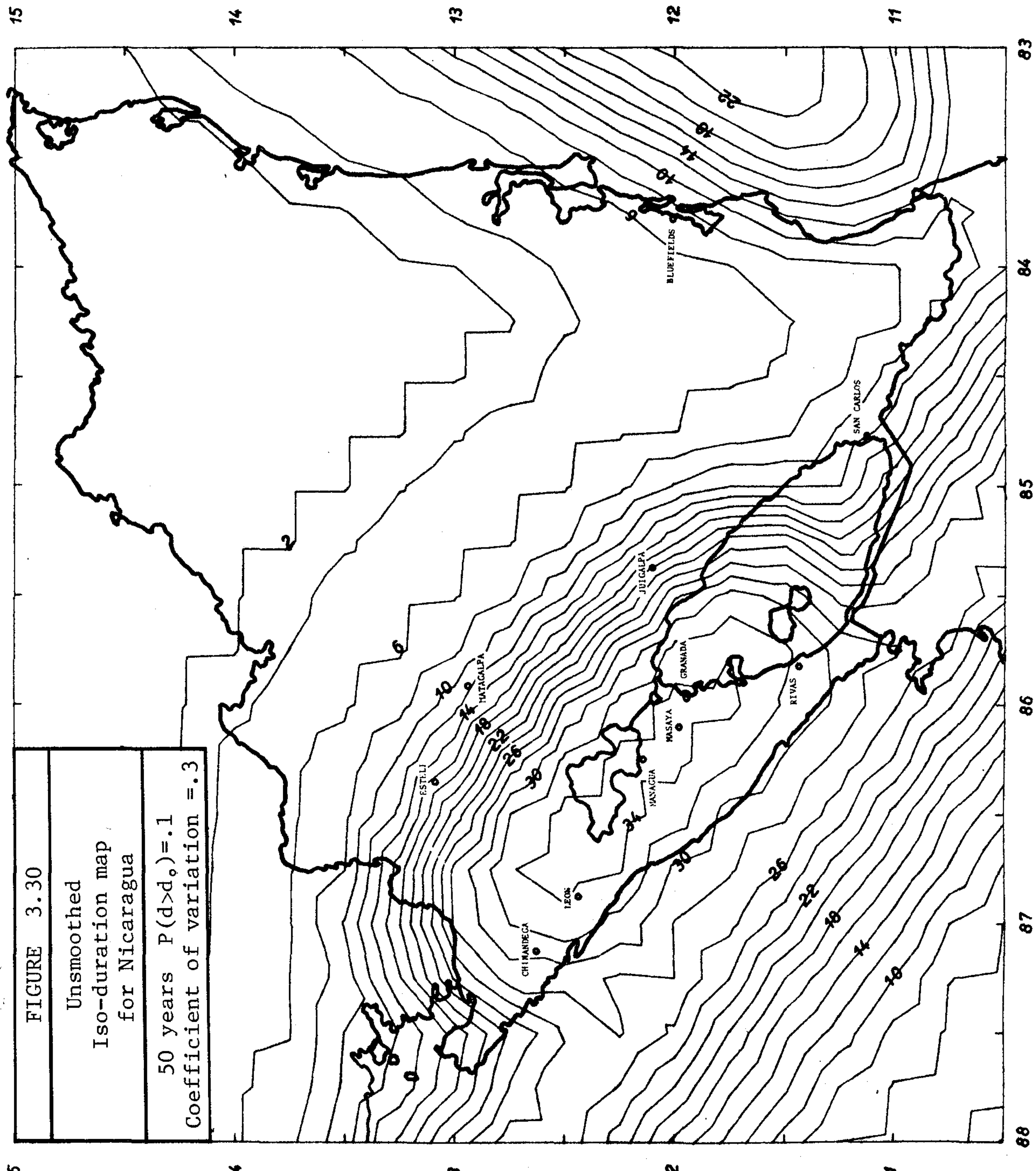


FIGURE 3.30

Unsmoothed Iso-duration map for Nicaragua

50 years $P(d>d_o)=.1$
Coefficient of variation =.3

also to emphasize the following points;

- The simplicity of incorporating any subjective information with the historical data to obtain Bayesian estimation on fault seismicity.
- The versatility of the method in which various uncertainties can be incorporated in obtaining the final probabilistic hazard information. In the example case, uncertainty in the attenuation equations was included through the coefficient of variation approach.
- The advantage of explicit probabilistic information on duration. This should be of great interest to engineers who wish to estimate the damage potential of a given event and also to researchers who are trying to develop seismic intensity parameters based on input energy, duration, amplitude, etc.
- The efficiency of the algorithm developed for mapping. Total information (CDF) for acceleration and duration was obtained for the 399 nodes of the grid. On a computer IBM 370/168, the execution time varied between 20 to 35 CPU seconds as a function of the value of the coefficient of variation in the attenuation relationships. (0.0 or 0.3).

It is hoped that the Bayesian methodology presented here will be applied to regions where there is very little historical data and where some subjective information on the local seismicity is available.

CHAPTER IV

ANALYSIS OF EARTHQUAKE RECORDS

4.1 Introduction

In Chapter I, Section 1.4.2 it is pointed out that an in depth study of earthquake records (accelerograms) involves time and frequency domain analyses. In the current analysis and design procedures, the time domain information is usually in the form of peak values (such as peak acceleration, velocity and displacement) and duration. The frequency domain information most widely used by engineers is in the form of response spectra (Newmark and Valestos, 1964). It is felt that such information is necessary but not sufficient and global for understanding earthquake ground motion. To develop a better understanding of currently available and digitized accelerograms, 97 records are analyzed in this study. As mentioned in Chapter I, the analysis involves the following parameters:

(A) Input parameters obtained from recorded accelerograms

- Duration (defined later in Section 4.2)
- Mean acceleration
- Root mean square (RMS) of acceleration
- Parameter a_p defined as the acceleration which has probability p of being exceeded for a given record.
- The ratio $K_1 = a_p/RMS$

(B) Response parameters obtained from acceleration response histories of a linear single degree of freedom system with damping ratios of 5%, 10% and 20% and natural period range of 0.08 sec to 5.0 sec.

- Duration (defined later in Section 4.4)

- Mean acceleration
- Peak response (corresponds to spectral value)
- RMS of acceleration
- Probability distribution of response peaks
- Parameter a_p defined as the response acceleration which has probability p of being exceeded for the given response.
- The ratio $K_1 = a_p/RMS$
- Cumulative potential energy per unit mass (ENGY) in the response time history.
- The ratio $K_2 = RMS^2 \cdot T^2/(ENGY/NBPK)$, where T is the period of the structure and NBPK is the number of peaks of the response time history.

4.2 Description of the Accelerograms Used

It is assumed herein that the digitized and corrected records of acceleration represent a true and sufficient input. These records are obtained on magnetic tape from the Earthquake Engineering Research Laboratory, California Institute of Technology. They correspond to the Volume II Report Series (Hudson, et al., 1971-1974). They are digitized at equal time increments of 0.02 seconds.

A set of 49 earthquakes is considered in this study (Table 4.1). No scaling of the amplitude is used. However, since duration is recognized to be of importance, some convention is necessary to define the duration of an earthquake record. Surprisingly, no standard (and acceptable) definition of duration exists in the literature. Whatever few references that are available define the duration qualitatively

#	RECORD NAME	CUTOFF (G)	DURATION (SEC)
A001	EL CENTRO 1940 SOUTH	.000	53.780
		.020	51.140
		.040	30.320
		.060	26.540
	EL CENTRO 1940 WEST	.000	53.500
		.020	50.820
		.040	29.660
		.060	26.760
A002	FERNDALE 1951 S44W	.000	55.920
		.020	14.760
		.040	7.780
		.060	4.540
	FERNDALE 1951 N46W	.000	55.920
		.020	13.440
		.040	9.580
		.060	4.740
A003	PASADENA 1952 SOUTH	.000	77.300
		.020	35.380
		.040	17.560
		.060	.000
	PASADENA 1952 WEST	.000	77.400
		.020	37.500
		.040	19.160
		.060	.000
A004	TAFT 1952 N21E	.000	54.400
		.020	44.920
		.040	29.900
		.060	18.600
	TAFT 1952 S69E	.000	54.420
		.020	45.700
		.040	18.840
		.060	17.480
A005	SANTA BARBARA 1952 N42E	.000	75.520
		.020	39.740
		.040	21.600
		.060	17.440
	SANTA BARBARA 1952 S48E	.000	75.500
		.020	43.560
		.040	20.680
		.060	9.880
A006	HOLLYWOOD 1952 BAS. SOUTH	.000	82.460
		.020	58.420
		.040	14.100
		.060	.000
	HOLLYWOOD 1952 BAS. EAST	.000	82.520
		.020	39.640
		.040	13.060
		.060	.000
A007	HOLLYWOOD 1952 PE. SOUTH	.000	78.660
		.020	58.660
		.040	18.040
		.060	.000
	HOLLYWOOD 1952 PE. EAST	.000	78.660
		.020	40.560
		.040	16.720
		.060	.000
A008	EUREKA 1954 N11W	.000	[illegible]
		.020	22.000
		.040	8.860
		.060	6.780
	EUREKA 1954 N79E	.000	79.500
		.020	29.920
		.040	11.040
		.060	9.260
A009	FERNDALE 1954 N44E	.000	42.340
		.020	30.140
		.040	18.320
		.060	17.540
	FERNDALE 1954 N46W	.000	42.420
		.020	27.520
		.040	24.180
		.060	14.760
A010	SAN JOSE 1955 N31W	.000	49.600
		.020	9.780
		.040	1.820
		.060	1.340
	SAN JOSE 1955 N59E	.000	51.780
		.020	9.020
		.040	1.400
		.060	1.400

TABLE 4.1. Earthquake Durations for Different Cutoff Levels

#	RECORD NAME	CUTOFF (G)	DURATION (SEC)
A011	EL CENTRO 1956 SOUTH	.000	90.060
		.020	32.400
		.040	.000
		.060	.000
	EL CENTRO 1956 WEST	.000	90.000
		.020	24.860
		.040	10.600
		.060	.000
A012	EL CENTRO AFTERSHOCK 1956 SOUTH	.000	88.140
		.020	.000
		.040	.000
		.060	.000
	EL CENTRO AFTERSHOCK 1956 WEST	.000	88.120
		.020	.000
		.040	.000
		.060	.000
A013	SOUTHERN PACIFIC 1957 N45E	.000	36.980
		.020	8.060
		.040	1.900
		.060	.000
	SOUTHERN PACIFIC 1957 N45W	.000	39.060
		.020	5.120
		.040	2.020
		.060	.000
A014	ALEXANDER BLDG. 1957 N09W	.000	39.720
		.020	3.660
		.040	2.780
		.060	.000
	ALEXANDER BLDG. 1957 N81E	.000	39.620
		.020	29.360
		.040	2.160
		.060	.000
A015	GOLDEN GATE 1957 N10E	.000	39.900
		.020	3.000
		.040	1.820
		.060	1.820
	GOLDEN GATE 1957 S80E	.000	39.900
		.020	4.060
		.040	2.840
		.060	1.980
A016	S F STATE BLDG 1957 S09E	.000	40.800
		.020	29.040
		.040	3.740
		.060	2.820
	S F STATE BLDG 1957 S81W	.000	40.740
		.020	26.960
		.040	2.600
		.060	.000
A017	OAKLAND 1957 N26E	.000	40.300
		.020	2.020
		.040	.000
		.060	.000
	OAKLAND 1957 S64E	.000	40.120
		.020	2.100
		.040	.000
		.060	.000
A018	HOLLISTER 1961 S01W	.000	40.500
		.020	20.160
		.040	12.040
		.060	1.180
	HOLLISTER 1961 N89W	.000	40.520
		.020	19.200
		.040	12.900
		.060	10.120
A019	BORREGO 1968 SOUTH	.000	87.440
		.020	35.640
		.040	21.280
		.060	9.420
	BORREGO 1968 WEST	.000	87.240
		.020	43.500
		.040	20.940
		.060	.000
A020	SAN DIEGO 1968 SOUTH	.000	79.220
		.020	13.480
		.040	.000
		.060	.000
	SAN DIEGO 1968 EAST	.000	79.260
		.020	11.340
		.040	.000
		.060	.000

TABLE 4.1. Earthquake Durations for Different Cutoff Levels (Cont.)

#	RECORD NAME	CUTOFF (G)	DURATION (SEC)
B021	LONG BEACH 1933 NOSE	.000	98.800
		.020	14.160
		.040	12.940
		.060	4.740
	LONG BEACH 1933 S82W	.000	98.460
		.020	23.580
		.040	11.700
		.060	2.720
B022	HOLLYWOOD PE. 1933 SOUTH	.000	89.780
		.020	22.140
		.040	.660
		.060	.000
	HOLLYWOOD PE. 1933 WEST	.000	89.680
		.020	21.920
		.040	10.920
		.060	5.360
B023	HOLLYWOOD BAS. 1933 SOUTH	.000	74.880
		.020	8.180
		.040	.000
		.060	.000
	HOLLYWOOD BAS. 1933 EAST	.000	74.840
		.020	.420
		.040	.000
		.060	.000
B024	EL CENTRO 1934 SOUTH	.000	90.320
		.020	34.940
		.040	24.060
		.060	15.120
	EL CENTRO 1934 WEST	.000	90.260
		.020	35.160
		.040	20.220
		.060	17.880
B025	HELENA 1935 NORTH	.000	50.940
		.020	4.960
		.040	3.500
		.060	3.280
	HELENA 1935 EAST	.000	51.040
		.020	4.920
		.040	3.740
		.060	3.360

#	RECORD NAME	CUTOFF (G)	DURATION (SEC)
B026	FERNDALE 1938 S45W	.000	71.400
		.020	12.400
		.040	6.800
		.060	5.580
	FERNDALE 1938 N45W	.000	71.400
		.020	8.620
		.040	6.080
		.060	3.280
B027	FERNDALE 1941 S45W	.000	67.300
		.020	8.920
		.040	5.560
		.060	5.560
	FERNDALE 1941 N45W	.000	67.280
		.020	6.380
		.040	.000
		.060	.000
B028	WASHINGTON 1949 S02W	.000	66.740
		.020	57.300
		.040	31.760
		.060	10.720
	WASHINGTON 1949 N88W	.000	66.720
		.020	51.380
		.040	23.220
		.060	13.120
B029	OLYMPIA 1949 S04E	.000	89.100
		.020	48.020
		.040	24.560
		.060	20.300
	OLYMPIA 1949 S86W	.000	89.080
		.020	49.760
		.040	25.440
		.060	21.600
B030	FERNDALE 1952 S44W	.000	57.900
		.020	9.620
		.040	7.260
		.060	.000
	FERNDALE 1952 N46W	.000	58.020
		.020	15.920
		.040	6.800
		.060	5.720

TABLE 4.1. Earthquake Durations for Different Cutoff Levels (Cont.)

#	RECORD NAME	CUTOFF (G)	DURATION (SEC)
B031	TAFT 1954 N21E	.000	65.420
		.020	13.200
		.040	6.280
		.060	5.840
	TAFT 1954 S69E	.000	65.380
		.020	15.100
		.040	7.420
		.060	6.540
B032	OLYMPIA 1965 S04E	.000	81.880
		.020	35.140
		.040	15.280
		.060	13.080
	OLYMPIA 1965 S86W	.000	81.980
		.020	29.580
		.040	23.260
		.060	12.500
B033	PARKFIELD A.2 1966 N65E	.000	43.680
		.020	26.560
		.040	14.500
		.060	13.720
B034	PARKFIELD A.5 1966 N05W	.000	43.960
		.020	19.880
		.040	13.900
		.060	12.800
	PARKFIELD A.5 1966 N85E	.000	43.980
		.020	20.940
		.040	15.460
		.060	12.200
B035	PARKFIELD A.8 1966 N05E	.000	26.220
		.020	20.540
		.040	13.440
		.060	9.620
	PARKFIELD A.8 1966 N40W	.000	26.180
		.020	21.000
		.040	10.820
		.060	7.260

#	RECORD NAME	CUTOFF (G)	DURATION (SEC)
B036	PARKFIELD A.12 1966 N50E	.000	44.280
		.020	20.180
		.040	7.420
		.060	.000
	PARKFIELD A.12 1966 N40W	.000	44.200
		.020	21.040
		.040	6.100
		.060	5.560
B037	TEMBLOR 1966 N65W	.000	30.380
		.020	11.120
		.040	8.160
		.060	6.180
	TEMBLOR 1966 S25W	.000	30.420
		.020	11.360
		.040	7.960
		.060	6.300
B038	SAN LUIS OBISPO 1966 N36W	.000	29.700
		.020	.000
		.040	.000
		.060	.000
	SAN LUIS OBISPO 1966 S54W	.000	29.740
		.020	.000
		.040	.000
		.060	.000
B039	EUREKA 1967 S11E	.000	30.020
		.020	1.120
		.040	.000
		.060	.000
	EUREKA 1967 N79E	.000	29.880
		.020	.000
		.040	.000
		.060	.000
B040	BORREGO 1968 N33E	.000	45.120
		.020	24.620
		.040	15.980
		.060	.000
	BORREGO 1968 N57W	.000	45.020
		.020	22.460
		.040	16.000
		.060	.000

TABLE 4.1. Earthquake Durations for Different Cutoff Levels (Cont.)

#	RECORD NAME	CUTOFF (G)	DURATION (SEC)
C041	PACOIMA DAM 1971 S16E	.000	41.840
		.020	40.420
		.040	34.200
		.060	33.740
	PACOIMA DAM 1971 S74W	.000	41.740
		.020	34.800
		.040	33.800
		.060	33.800
C048	ORION BLDG 1971 NORTH	.000	59.520
		.020	38.660
		.040	20.780
		.060	19.600
	ORION BLDG 1971 WEST	.000	59.620
		.020	38.860
		.040	22.460
		.060	20.800
C051	EAST FIRST ST 1971 N36E	.000	52.560
		.020	30.040
		.040	10.640
		.060	8.540
	EAST FIRST ST 1971 N54W	.000	52.320
		.020	16.700
		.040	8.040
		.060	6.820
C054	FIGUEROA ST 1971 N52W	.000	57.300
		.020	16.960
		.040	8.980
		.060	7.760
	FIGUEROA ST 1971 S38W	.000	57.320
		.020	19.820
		.040	12.700
		.060	6.540
D057	HOLLYWOOD ST BAS. 1971 SOUTH	.000	82.160
		.020	18.220
		.040	12.920
		.060	10.180
	HOLLYWOOD ST BAS. 1971 EAST	.000	82.140
		.020	30.900
		.040	13.820
		.060	9.560
D058	HOLLYWOOD ST PE. 1971 SOUTH	.000	79.500
		.020	31.800
		.040	12.860
		.060	7.620
	HOLLYWOOD ST PE. 1971 EAST	.000	79.500
		.020	31.740
		.040	11.580
		.060	9.560
G106	CALTECH LAB 1971 SOUTH	.000	99.020
		.020	12.960
		.040	8.880
		.060	7.500
	CALTECH LAB 1971 WEST	.000	99.020
		.020	16.380
		.040	9.420
		.060	8.200
J141	LAKE HUGHES A1 1971 N21E	.000	60.220
		.020	21.260
		.040	15.360
		.060	5.020
	LAKE HUGHES A1 1971 S69E	.000	60.280
		.020	20.980
		.040	16.480
		.060	6.840
J142	LAKE HUGHES A4 1971 S69E	.000	37.040
		.020	18.540
		.040	6.960
		.060	6.300
	LAKE HUGHES A4 1971 S21W	.000	37.040
		.020	16.680
		.040	8.500
		.060	6.040
J143	LAKE HUGHES A9 1971 N21E	.000	35.000
		.020	12.680
		.040	4.920
		.060	3.580
	LAKE HUGHES A9 1971 N69W	.000	35.040
		.020	12.860
		.040	3.600
		.060	3.600

TABLE 4.1. Earthquake Durations for Different Cutoff Levels (Cont.)

#	RECORD NAME	CUTOFF (G)	DURATION (SEC)
J144	LAKE HUGHES A12 1971 N21E	.000	36.640
		.020	22.620
		.040	15.000
		.060	12.120
	LAKE HUGHES A12 1971 N69W	.000	36.760
		.020	19.060
		.040	14.580
		.060	10.300
L166	LANKERSHIM 1971 NORTH	.000	65.360
		.020	19.260
		.040	10.500
		.060	7.540
	LANKERSHIM 1971 WEST	.000	65.200
		.020	19.020
		.040	8.840
		.060	7.460

TABLE 4.1. Earthquake Durations for Different Cutoff Levels (Cont.)

(i.e., the time during which the damage is likely to occur). To develop a simple and usable definition of record duration, a sensitivity study of the effects of various levels of acceleration cutoffs on the duration is conducted. Table 4.1 gives the results of this study. After inspection of these results, it was decided to use 0.02G level of acceleration as the cutoff acceleration. In other words, the record is truncated at the time when the acceleration becomes and remains smaller than 0.02G. This is a rather arbitrary definition; however, for this study, it seems to be a reasonable definition.

Because of the above definition of duration, three earthquake records are totally eliminated, their peak ground accelerations being smaller than 0.02G. The total number of records analyzed is thus 97 noting that the Parkfield A.2 1966 earthquake has only one component recorded (record B033 in Hudson, et al.,1972). These records are chosen to provide a large spectrum of earthquakes recorded on different soil conditions and at various distances from the epicenters.

Only horizontal accelerations have been considered in the study. The parameters mean, RMS and a_p have been computed using both the peak values and the values corresponding to the equal time increments (the input and responses being digitized at equal time increments). The parameters values (mean, RMS and a_p) obtained from both methods are proportional. Hence they are related by a constant and the conclusions drawn for one set of parameters can be applied to the other. In the following sections only the results based on the incremental values are presented.

4.3 Statistics of the Input Parameters

The first step in the analysis of past earthquake data is to evaluate the various input and statistical parameters associated with the recorded and digitized accelerograms. Table 4.2 shows the results of this analysis. Each of the parameters analyzed is described below;

- NBPK (Column 4)

  This parameter represents the number of peaks of the earthquake records. Strictly, NBPK represents the number of zero crossings of the given accelerogram. This information is useful in calculating the RMS of the record.

- RMS (Column 5)

  This parameter is a statistical summary of all the incremental values recorded for a given accelerogram. In terms of the frequency domain, the RMS of the input is the ordinate of RMS vs. period graph at zero period. This information is extensively used in developing a stable parameter described in later sections. The RMS for all the records is calculated using the following expression.

$$\mathrm{RMS} = \sqrt{\frac{\Sigma\, h_i^2}{n-1}} \qquad (4.1)$$

where h_i = individual acceleration amplitude

n = total number of time increments.

This parameter is a better description of the accelerogram than the peak value representation currently used. Also, being a statistical summary, its variation is less than the variation of the peaks.

#	RECORD NAME	PGA (G)	NBPK	RMS (G)	LAMBDA	P(A>A*) A* P=5%	P(A>A*) A* P=10%	K1 P=5%	K1 P=10%
A001	EL CENTRO 1940 SOUTH	.348	315	.048	35.43	.085	.065	1.760	1.353
	EL CENTRO 1940 WEST	.214	296	.041	38.07	.079	.060	1.939	1.491
A002	FERNDALE 1951 S44W	.104	106	.019	73.14	.041	.031	2.144	1.648
	FERNDALE 1951 N46W	.112	98	.022	63.96	.047	.036	2.092	1.608
A003	PASADENA 1952 SOUTH	.047	178	.010	143.88	.021	.016	2.079	1.598
	PASADENA 1952 WEST	.053	157	.014	106.04	.028	.022	2.090	1.606
A004	TAFT 1952 N21E	.156	298	.028	53.15	.056	.043	2.017	1.551
	TAFT 1952 S69E	.179	300	.029	51.90	.058	.044	1.995	1.534
A005	SANTA BARBARA 1952 N42E	.090	170	.019	76.74	.039	.030	2.014	1.548
	SANTA BARBARA 1952 S48E	.131	177	.020	74.00	.040	.031	1.990	1.530
A006	HOLLYWOOD 1952 BAS. SOUTH	.055	215	.012	110.50	.027	.021	2.201	1.692
	HOLLYWOOD 1952 BAS. EAST	.044	201	.012	111.12	.027	.021	2.202	1.693
A007	HOLLYWOOD 1952 PE. SOUTH	.059	245	.013	108.35	.028	.021	2.210	1.698
	HOLLYWOOD 1952 PE. EAST	.042	230	.012	110.91	.027	.021	2.208	1.697
A008	EUREKA 1954 N11W	.168	103	.031	54.73	.055	.042	1.761	1.353
	EUREKA 1954 N79E	.258	104	.039	48.86	.061	.047	1.556	1.196
A009	FERNDALE 1954 N44E	.159	100	.034	44.71	.067	.052	1.965	1.510
	FERNDALE 1954 N46W	.201	110	.029	55.59	.054	.041	1.846	1.419
A010	SAN JOSE 1955 N31W	.102	65	.021	71.65	.042	.032	1.946	1.495
	SAN JOSE 1955 N59E	.108	73	.019	82.71	.036	.028	1.934	1.487
A011	EL CENTRO 1956 SOUTH	.033	147	.010	133.57	.022	.017	2.315	1.780
	EL CENTRO 1956 WEST	.051	100	.015	84.83	.035	.027	2.379	1.829
A013	SOUTHERN PACIFIC 1957 N45E	.047	55	.011	117.65	.025	.020	2.312	1.777
	SOUTHERN PACIFIC 1957 N45W	.046	34	.017	72.52	.041	.032	2.403	1.847

TABLE 4.2. Listing of Input Parameters

#	RECORD NAME	PGA (G)	NBPK	RMS (G)	LAMBDA	P(A>A*) A* P=5%	P(A>A*) A* P=10%	K1 P=5%	K1 P=10%
A014	ALEXANDER BLDG 1957 N09W	.043	36	.014	97.68	.031	.024	2.197	1.688
	ALEXANDER BLDG 1957 N81E	.046	236	.005	341.02	.009	.007	1.618	1.243
A015	GOLDEN GATE 1957 N10E	.083	45	.023	63.95	.047	.036	2.018	1.551
	GOLDEN GATE 1957 S80E	.105	61	.027	57.64	.052	.040	1.909	1.467
A016	S F STATE BLDG 1957 S09E	.065	192	.011	192.93	.016	.012	1.445	1.110
	S F STATE BLDG 1957 S81W	.056	206	.009	229.04	.013	.010	1.518	1.167
A017	OAKLAND 1957 N26E	.040	20	.014	93.25	.032	.025	2.292	1.761
	OAKLAND 1957 S64E	.024	22	.009	149.68	.020	.015	2.248	1.728
A018	HOLLISTER 1961 S01W	.065	82	.020	63.87	.047	.036	2.319	1.782
	HOLLISTER 1961 N89W	.179	76	.029	48.73	.061	.047	2.098	1.613
A019	BORREGO 1968 SOUTH	.130	187	.020	73.70	.041	.031	2.065	1.587
	BORREGO 1968 WEST	.057	214	.014	93.39	.032	.025	2.263	1.740
A020	SAN DIEGO 1968 SOUTH	.030	75	.007	214.71	.014	.011	1.972	1.515
	SAN DIEGO 1968 EAST	.029	57	.007	214.13	.014	.011	1.991	1.530
B021	LONG BEACH 1933 N08E	.133	69	.031	43.28	.069	.053	2.239	1.721
	LONG BEACH 1933 S82W	.154	122	.022	67.65	.044	.034	2.004	1.540
B022	HOLLYWOOD PE. 1933 SOUTH	.044	74	.013	93.14	.032	.025	2.515	1.933
	HOLLYWOOD PE. 1933 WEST	.087	83	.026	50.21	.060	.046	2.326	1.788
B023	HOLLYWOOD BAS. 1933 SOUTH	.033	47	.007	184.80	.016	.012	2.213	1.701
	HOLLYWOOD BAS. 1933 EAST	.027	2	.015	81.56	.037	.028	2.450	1.884
B024	EL CENTRO 1934 SOUTH	.160	223	.032	46.80	.064	.049	2.026	1.557
	EL CENTRO 1934 WEST	.183	221	.034	44.96	.067	.051	1.986	1.526
B025	HELENA 1935 NORTH	.146	62	.030	51.24	.058	.045	1.918	1.474
	HELENA 1935 EAST	.145	67	.038	41.57	.072	.055	1.874	1.440

TABLE 4.2. Listing of Input Parameters (Cont.)

#	RECORD NAME	PGA (G)	NHPK	RMS (G)	LAMBDA	P(A>A*) A* P=5%	P(A>A*) A* P=10%	K1 P=5%	K1 P=10%
B026	FERNDALE 1938 S45W	.144	89	.022	65.90	.045	.035	2.032	1.562
	FERNDALE 1938 N45W	.089	72	.022	64.96	.046	.035	2.118	1.628
B027	FERNDALE 1941 S45W	.062	54	.016	82.66	.036	.028	2.311	1.776
	FERNDALE 1941 N45W	.039	43	.015	83.52	.036	.028	2.460	1.891
B028	WASHINGTON 1949 S02W	.068	254	.015	92.65	.032	.025	2.141	1.646
	WASHINGTON 1949 N88W	.067	251	.013	107.21	.028	.021	2.152	1.654
B029	OLYMPIA 1949 S04E	.165	351	.032	49.57	.060	.046	1.906	1.465
	OLYMPIA 1949 S86W	.280	368	.058	42.07	.071	.055	1.666	1.434
B030	FERNDALE 1952 S44W	.054	81	.017	90.06	.033	.026	2.004	1.540
	FERNDALE 1952 N46W	.076	109	.014	108.17	.028	.021	2.005	1.541
B031	TAFT 1954 N21E	.065	115	.013	125.86	.024	.018	1.891	1.454
	TAFT 1954 S69E	.068	124	.013	107.58	.028	.021	2.083	1.601
B032	OLYMPIA 1965 S04E	.137	534	.023	68.05	.044	.034	1.892	1.454
	OLYMPIA 1965 S86W	.198	297	.031	48.98	.061	.047	1.977	1.519
B033	PARKFIELD A.2 1966 N65E	.489	121	.066	30.99	.097	.074	1.456	1.119
B034	PARKFIELD A.5 1966 N05W	.355	186	.045	40.99	.073	.056	1.634	1.256
	PARKFIELD A.5 1966 N85E	.434	157	.051	36.41	.082	.063	1.614	1.241
B035	PARKFIELD A.8 1966 N05E	.237	141	.031	48.76	.061	.047	1.990	1.529
	PARKFIELD A.8 1966 N40W	.275	162	.034	48.65	.062	.047	1.810	1.391
B036	PARKFIELD A.12 1966 N50E	.053	175	.012	108.91	.028	.021	2.277	1.750
	PARKFIELD A.12 1966 N40W	.064	188	.013	101.75	.029	.023	2.311	1.776
B037	TEMBLOR 1966 N65W	.269	84	.042	43.06	.070	.053	1.675	1.287
	TEMBLOR 1966 S25W	.347	80	.050	36.80	.081	.063	1.617	1.243
B040	BORREGO 1968 N33E	.041	192	.008	183.68	.016	.013	2.102	1.616
	BORREGO 1968 N57W	.046	141	.009	152.30	.020	.015	2.137	1.642

TABLE 4.2. Listing of Input Parameters (Cont.)

#	RECORD NAME	PGA (G)	NBPK	RMS (G)	LAMBDA	P(A>A*) A* P=5%	P(A>A*) A* P=10%	K1 P=5%	K1 P=10%
C041	PACOIMA DAM 1971 S16E	1.170	412	.116	19.35	.155	.119	1.332	1.024
	PACOIMA DAM 1971 S74W	1.075	380	.120	17.56	.171	.131	1.422	1.093
C048	ORION BLDG 1971 NORTH	.255	175	.046	34.22	.086	.067	1.900	1.460
	ORION BLDG 1971 WEST	.154	158	.033	43.27	.069	.053	2.078	1.597
C051	EAST FIRST ST 1971 N36E	.100	207	.021	73.34	.041	.031	1.921	1.476
	EAST FIRST ST 1971 N	.125	129	.028	49.42	.061	.047	2.164	1.663
C054	FIGUEROA ST 1971 N52W	.150	125	.028	55.14	.054	.042	1.911	1.469
	FIGUEROA ST 1971 S38W	.119	150	.026	54.72	.055	.042	2.136	1.642
D057	HOLLYWOOD ST BAS. 1971 SOUTH	.106	120	.028	50.10	.060	.046	2.158	1.659
	HOLLYWOOD ST BAS. 1971 EAST	.151	137	.028	57.54	.052	.040	1.859	1.429
D058	HOLLYWOOD ST PE. 1971 SOUTH	.171	283	.029	58.81	.051	.039	1.775	1.364
	HOLLYWOOD ST PE. 1971 EAST	.211	225	.036	48.15	.062	.048	1.727	1.328
G106	CALTECH LAB 1971 SOUTH	.089	143	.023	58.93	.051	.039	2.214	1.702
	CALTECH LAB 1971 WEST	.192	177	.036	44.05	.068	.052	1.865	1.433
J141	LAKE HUGHES A1 1971 N21E	.148	117	.028	54.23	.055	.042	1.998	1.535
	LAKE HUGHES A1 1971 S69E	.111	142	.024	55.93	.054	.041	2.239	1.721
J142	LAKE HUGHES A4 1971 S69E	.171	305	.027	57.18	.052	.040	1.917	1.474
	LAKE HUGHES A4 1971 S21W	.146	248	.027	55.32	.054	.042	2.012	1.546
J143	LAKE HUGHES A9 1971 N21E	.122	176	.024	64.48	.046	.036	1.973	1.517
	LAKE HUGHES A9 1971 N69W	.112	176	.021	73.84	.041	.031	1.928	1.482
J144	LAKE HUGHES A12 1971 N21E	.353	260	.050	34.25	.087	.067	1.738	1.336
	LAKE HUGHES A12 1971 N69W	.283	218	.051	32.10	.093	.072	1.846	1.419
L166	LANKERSHIM 1971 NORTH	.167	157	.025	59.30	.051	.039	2.006	1.544
	LANKERSHIM 1971 WEST	.150	152	.031	49.31	.061	.047	1.940	1.491

TABLE 4.2. Listing of Input Parameters (Cont.)

- Probability distribution function of amplitude values at equal time increments.

To understand the variability and distribution of the accelerogram amplitudes, various probability functions are tried considering the amplitude values as a random variable. In particular two distributions seem to fit the data quite well. They are the gamma and the exponential distributions. Figure 4.1 shows two typical CDF fits of gamma and exponential distributions to accelerograms. After trying these two distributions for all the accelerograms considered, it is decided to use the exponential form because it is simple to use and fits the data reasonably well. The probability distribution function for exponential shape (Fig. 4.2) is given by

$$f_A(a) = \lambda e^{-\lambda a} \tag{4.2}$$

where A = random variable defining the acceleration amplitude

a = the value A takes

λ = constant of the exponential distribution

It should be pointed out that once the distribution of the amplitudes is known, any probability statement regarding the acceleration can be made. As an example:

$$\begin{aligned} P(\text{Peak amplitude } A \geq a) &= \int_a^\infty \lambda e^{-\lambda A} dA \\ &= e^{-\lambda a} \end{aligned} \tag{4.3}$$

This information is extensively used in determining a_p defined below and in obtaining the stable parameter K_1

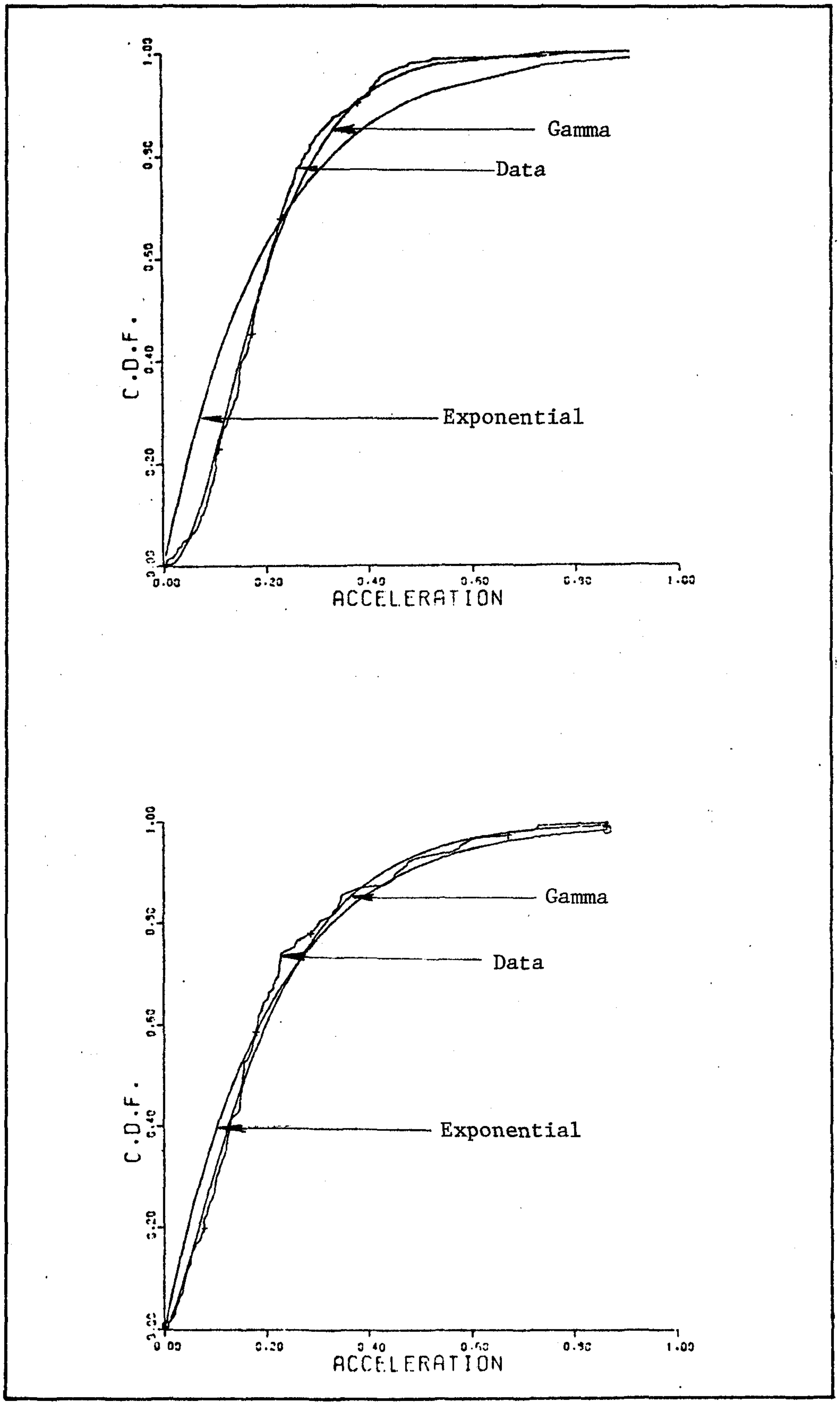


FIGURE 4.1. Two Typical Gamma and Exponential Fits of Earthquake Record Amplitudes.

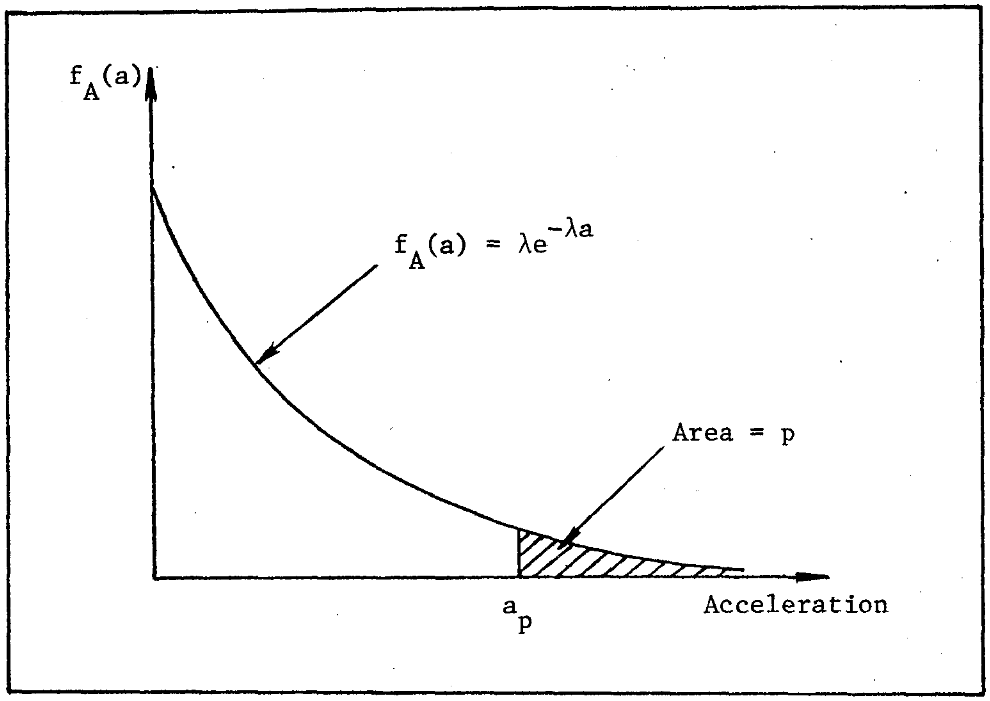


FIGURE 4.2. Exponential Distribution

- Mean acceleration (Column 6:λ)

  This parameter is the average amplitude of the acceleration throughout the record. It is equal to $1/\lambda$ where λ is the parameter of the exponential distribution.

- a_p (Column 7: $p = 5\%$; Column 8: $p = 10\%$)

  This variable represents the acceleration which has p probability of exceedence for a given accelerogram (Fig. 4.2).

- Ratio $K_1 = a_p/\text{RMS}$ (Column 9: $p = 5\%$; Column 10: $p = 10\%$)

  As will be described in Section 4.4, this ratio is truly stable for all accelerograms with the exception of few records.

The reasons for developing the parameters presented in Table 4.2 are:

- To numerically summarize the relevant parameters describing the recorded seismic event.
- To look at the behavior of the summary parameters for trends and similarities
- To obtain the values of response parameters in the frequency domain at zero period
- To obtain a stable input parameter which could be used for a better description of the recorded event.

It should be noted that even though the values of a_p and RMS varies substantially from one accelerogram to another, the value of the ratio $K_1 = a_p/RMS$ remains essentially constant.

4.4 Statistics of the Response Parameters

As mentioned in Chapter I, the proper understanding of a given earthquake time history requires a time and frequency domain analysis. In Section 4.3, all the relevant time domain parameters as well as the frequency domain parameters for zero period are presented. In this section, the response parameters corresponding to the 97 accelerograms are evaluated and presented.

The response parameter most widely used by engineers is the response spectrum value . This value is a good representation of a single degree of freedom system to a given accelerogram. However, it is not sufficient information. For this reason, a complete analysis of the response parameters is presented in this section. Figure 4.3 shows

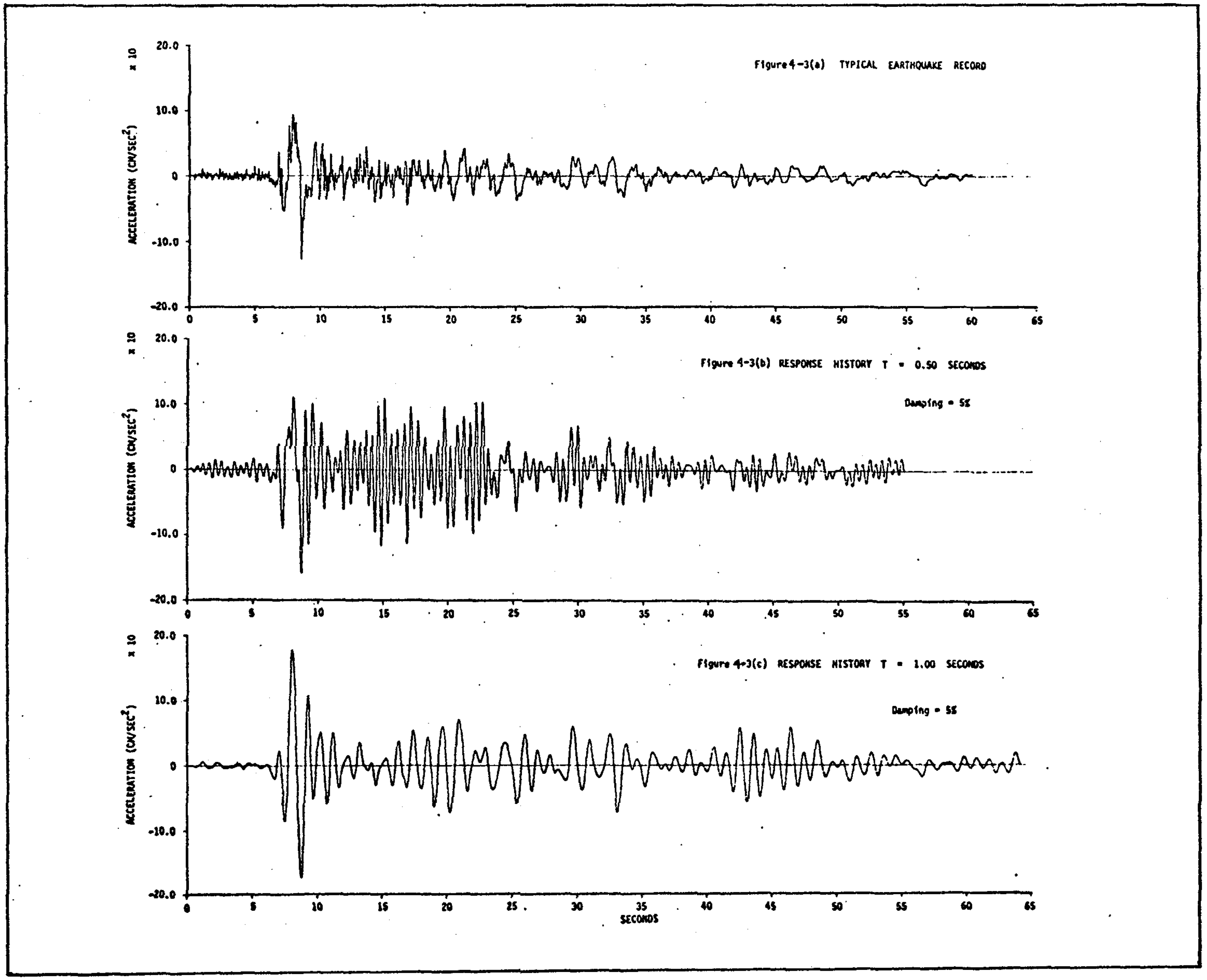


FIGURE 4.3. Typical Earthquake Record and Response Time Histories

a typical earthquake accelerogram and the responses of a one degree of freedom system (for given periods and damping). The current procedure is to look at the largest response peak, corresponding to a given damping ratio (say 5%) and period (say 0.50 sec and 1.0 sec) of the vibratory system. The highest response peaks then represent the response spectrum values corresponding to the period and damping considered.

In this study, the following parameters are evaluated for each response time history (acceleration only)

- Number of peaks (NBPK)
- Duration of the response
- Spectral acceleration response
- RMS of acceleration response
- Mean acceleration response
- Probability distribution function of response accelerations
- Parameters a_p defined as the response acceleration of a given one degree of freedom system subjected to a given accelerogram and which has probability p of being exceeded.
- Cumulative potential energy per unit mass (ENGY) in the response time acceleration history
- The ratio $K_1 = a_p/\mathrm{RMS}$ for each response history
- The ratio $K_2 = \mathrm{RMS}^2 \cdot T^2/(\mathrm{ENGY}/\mathrm{NBPK})$ for each response history

For each of the 97 accelerograms, 60 single degree of freedom systems varying in periods from 0.08 sec to 5.0 sec are considered. The damping ratio of 5% is kept constant for all the cases. (In fewer instances dampings of 10% and 20% are also considered.) Thus, for each accelerogram, 60 response time histories are analyzed to obtain the response parameters mentioned above.

The first decision to make in analyzing the responses concerns the duration of the response. Surprisingly, no work is available in the literature defining the duration of the response record. Unless a convention (or standard) is used to define the duration, it is not possible to evaluate parameters such as RMS, NBPK and ENGY. Hence, it is somewhat arbitrarily decided to terminate the response when the amplitude of the response acceleration peak reaches 10% of the highest response peak and does not exceed that value thereafter. This convention fixes the response duration. Another way of defining this parameter would be to consider the response duration as a function of input duration, the period of the oscillator under consideration and the damping of the system. More research is needed to rationally evaluate this parameter.

The response parameters analyzed are listed for all earthquakes in Appendix B. They are describes below.

- NBPK (Column 2)

  This parameter represents the number of zero crossings of the given response history. It is useful in computing the RMS and the factors K_1 and K_2 described later in this section.

- Duration (Column 3)

  This parameter represents the duration of the response in seconds. It is the time for which the response acceleration amplitude (for a given oscillator) remains greater than 10% of the highest response acceleration.

- Spectral response acceleration (Column 4)

  This parameter is the amplitude of the largest peak of the response. It corresponds to the widely used acceleration response spectrum.

- RMS (Column 5)

  This parameter is a statistical summary of the acceleration amplitudes at equal time increments (Hald, 1952). For each period it is computed as

$$\mathrm{RMS} = \sqrt{\frac{\Sigma h_i^2}{n-1}} \qquad (4.4)$$

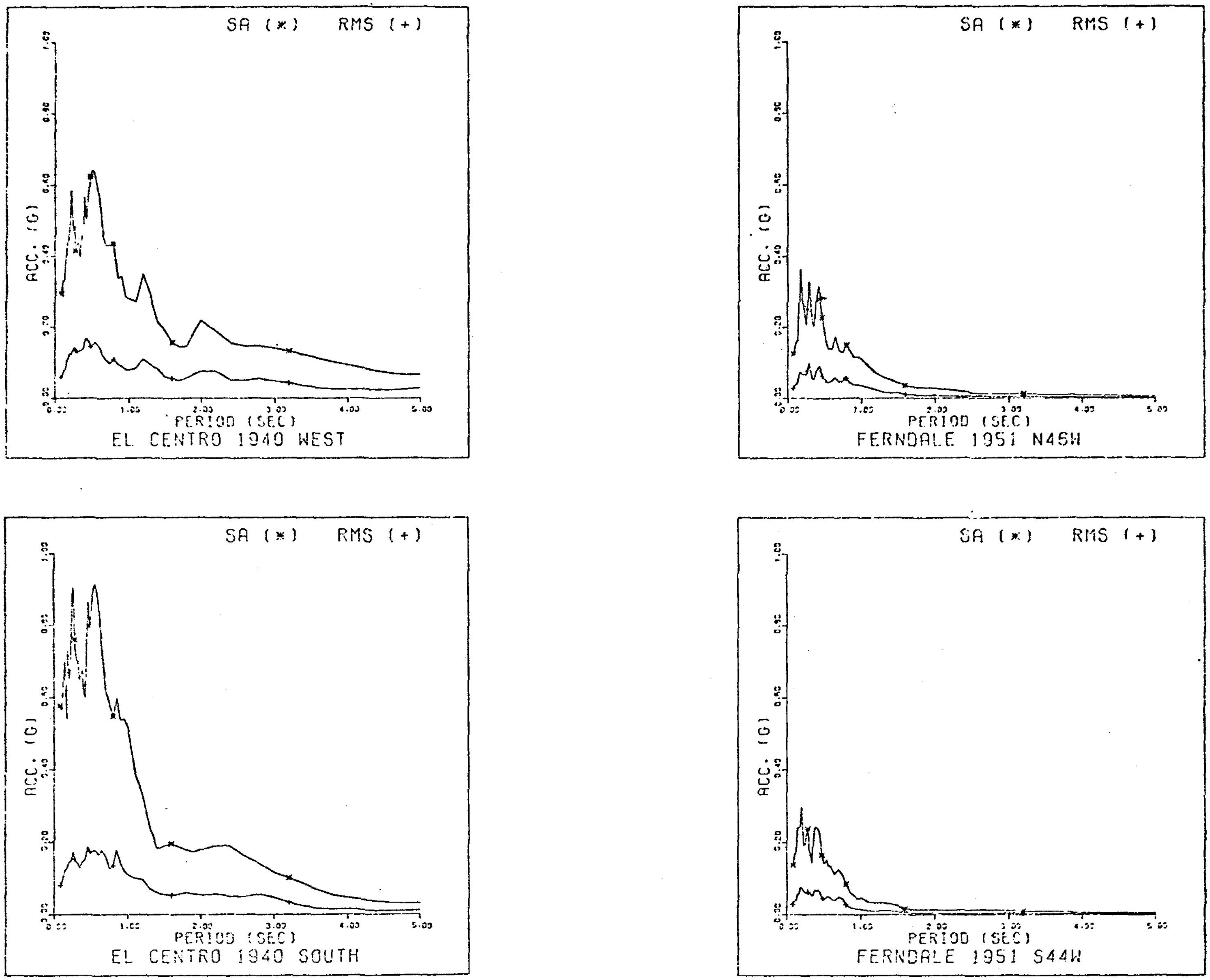
  where h_i = acceleration amplitude at equal time increments

  n = total number of increments

  This parameter gives a better statistical description of the response than the peak values S_a. Being a statistical summary its variation is less than the variation of the peaks particularly for short period ($T < .2$ sec) which are more susceptible to phase shift as well as subtraction and addition of waves. Figure 4.4 gives to the same scale the corresponding S_a and RMS spectrum for all the records. The RMS is used in the determination of factors K_1 and K_2.

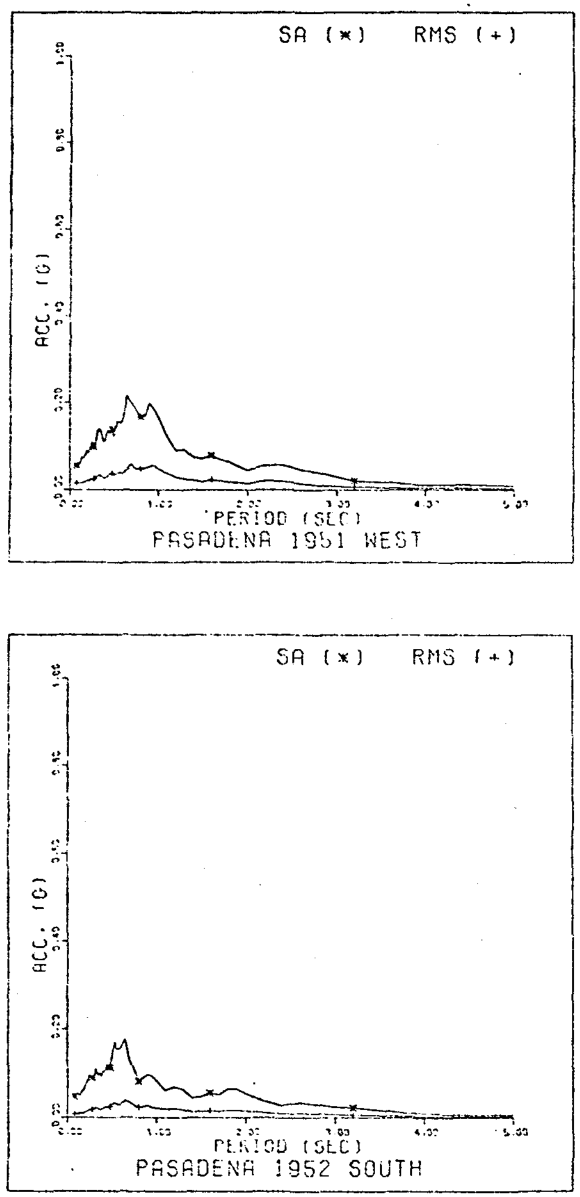
- Probability distribution function of acceleration amplitudes.

  To understand the variability and distribution of the response acceleration, various probability functions are tried considering the amplitude values as a random variable. Here again, the gamma distribution shows a somewhat better fit than the exponential distribution. However for simplicity

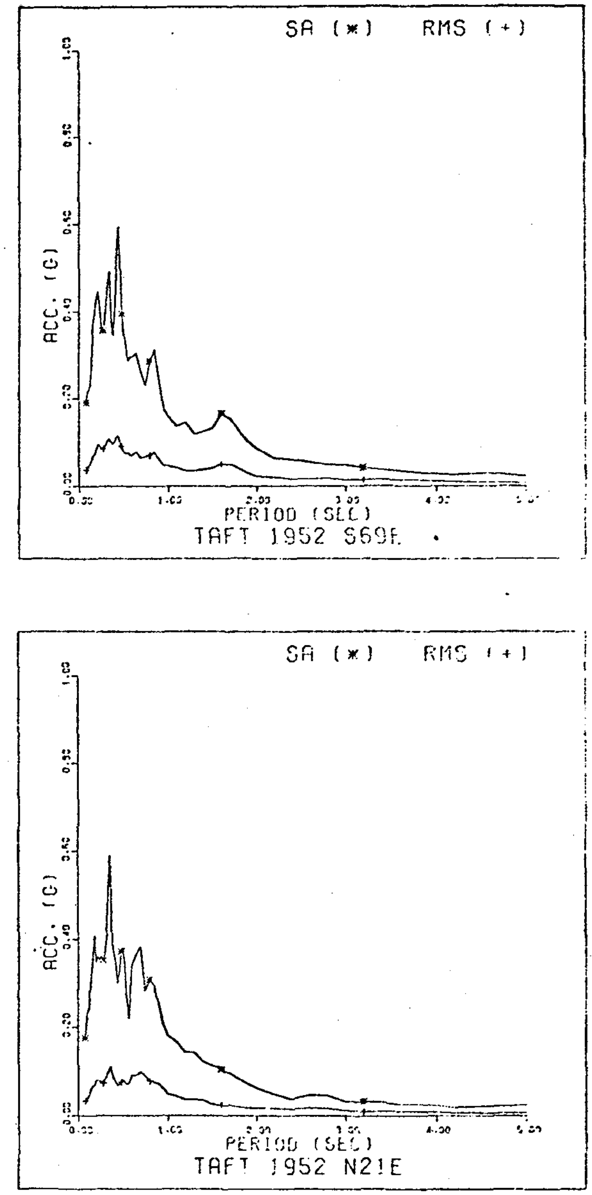


(A001) (A002)

FIGURE 4.4. Acceleration and **RMS** Response Spectra

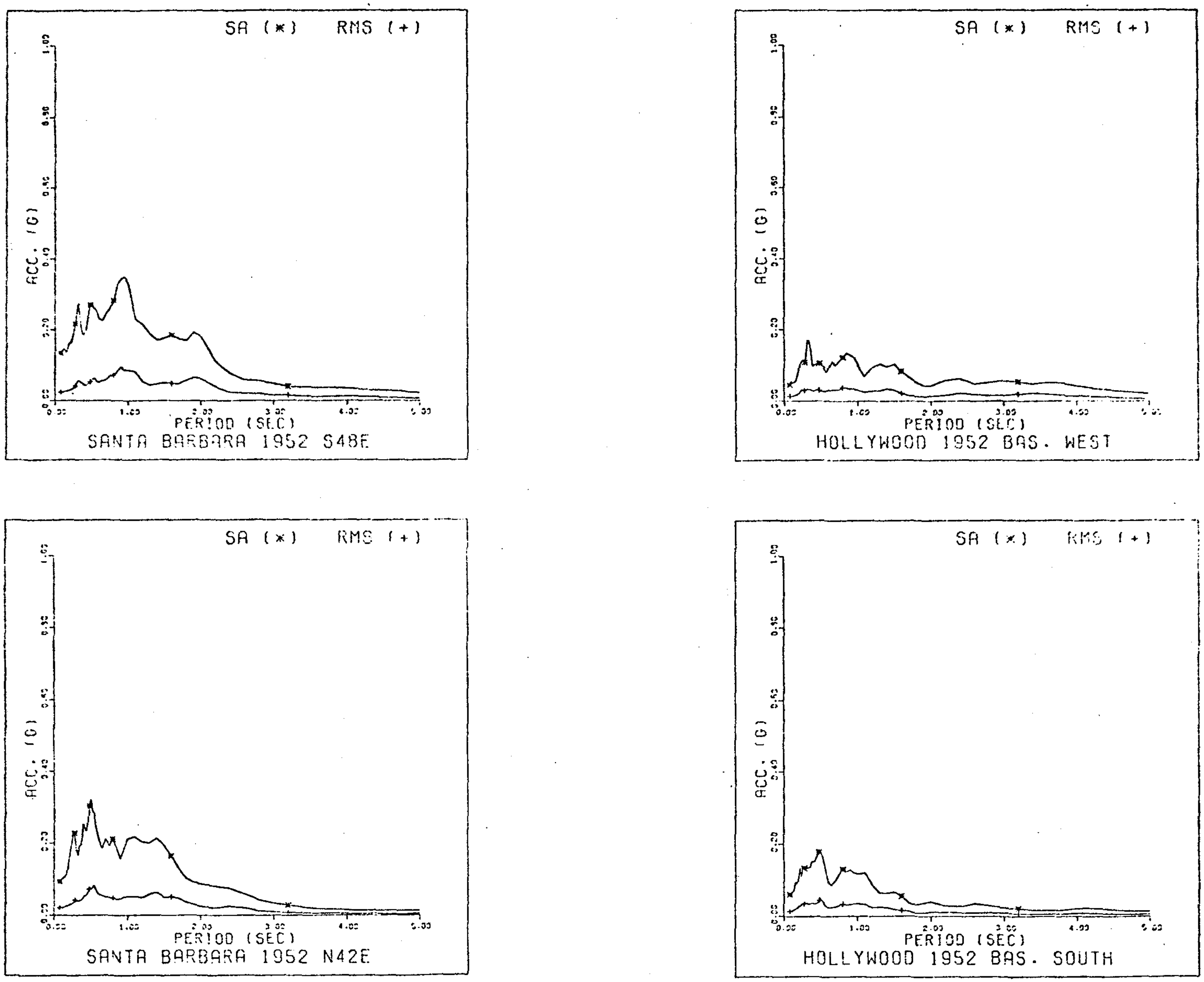


(A003)



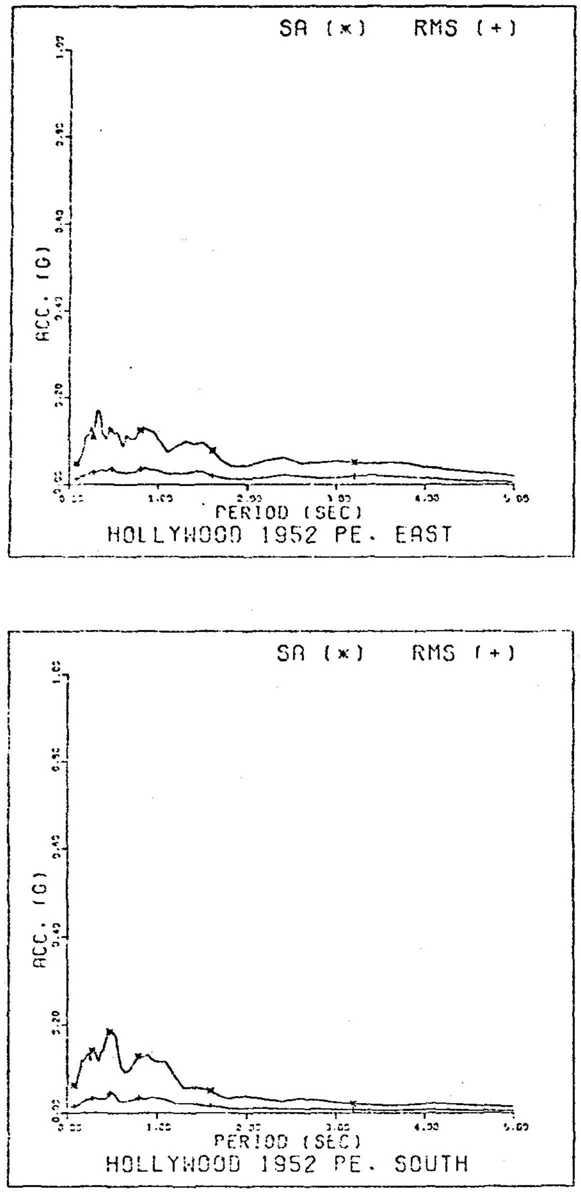
(A004)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

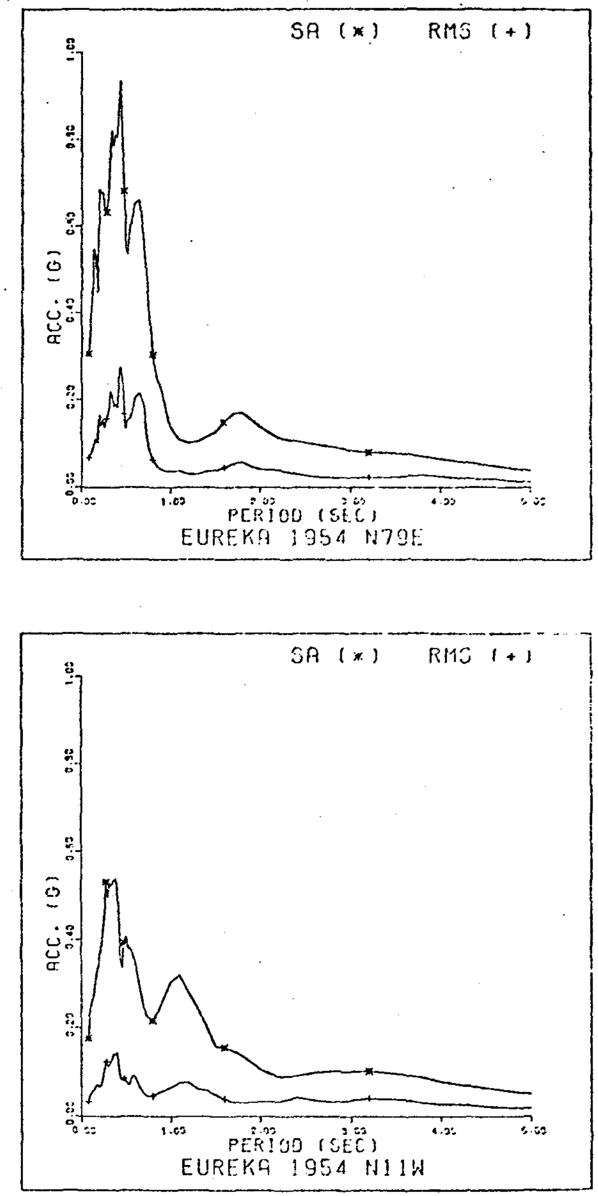


(A005) (A006)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

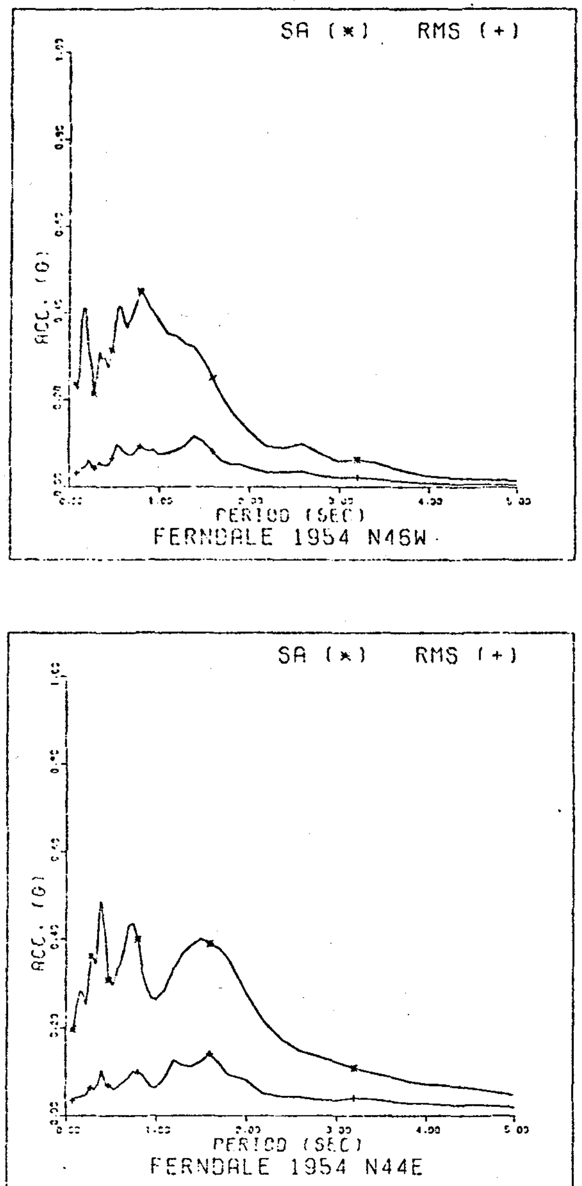


(A007)

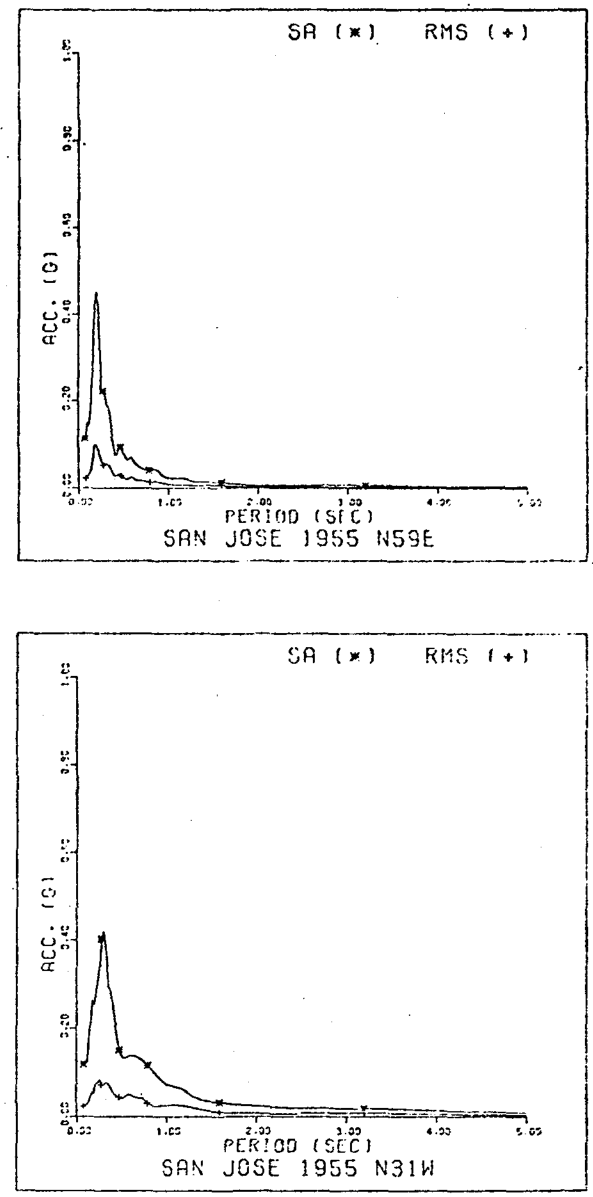


(A008)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

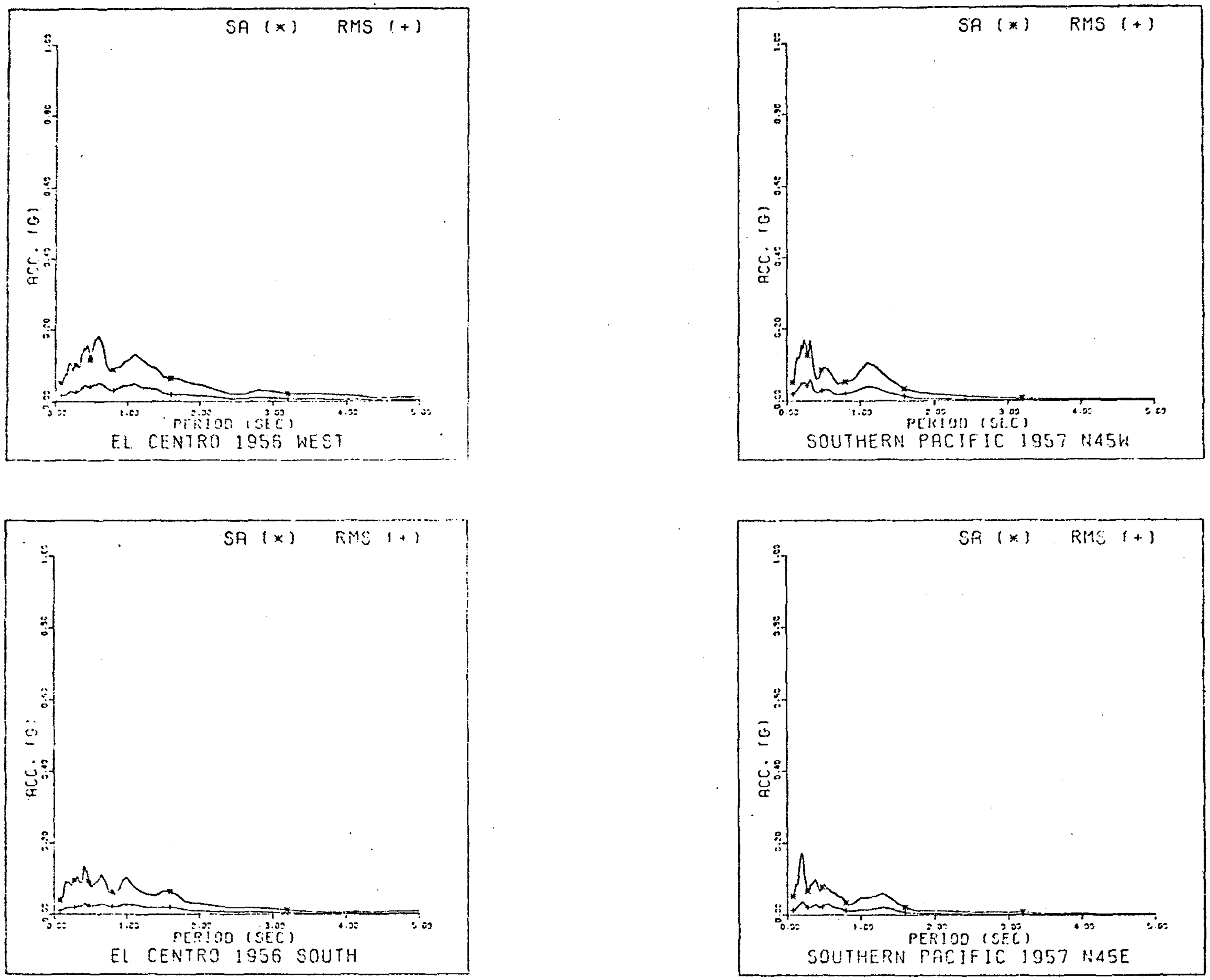


(A009)



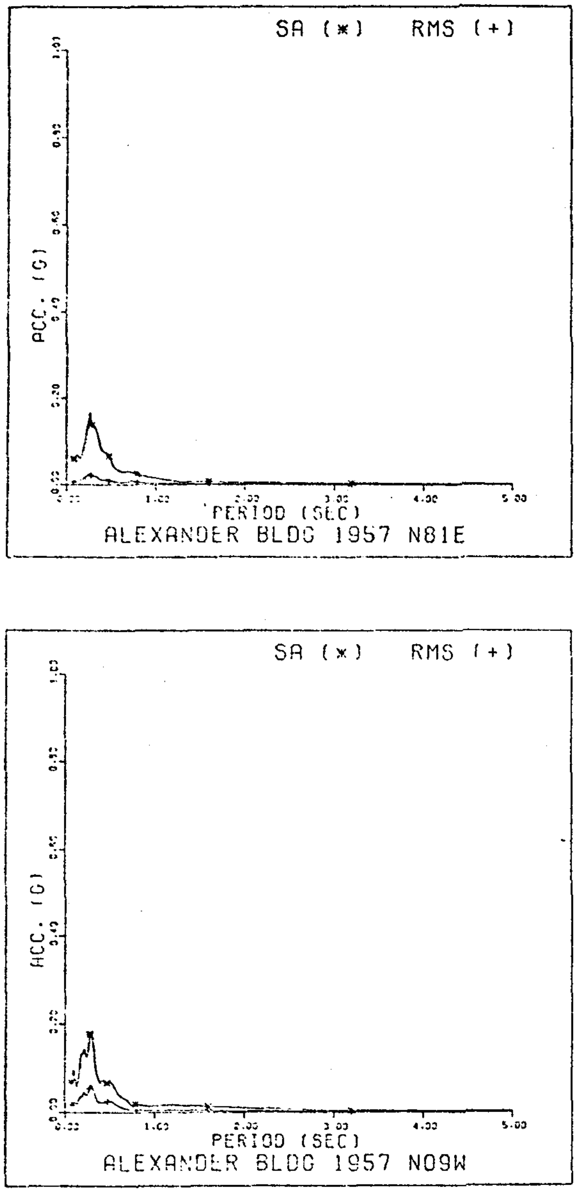
(A010)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

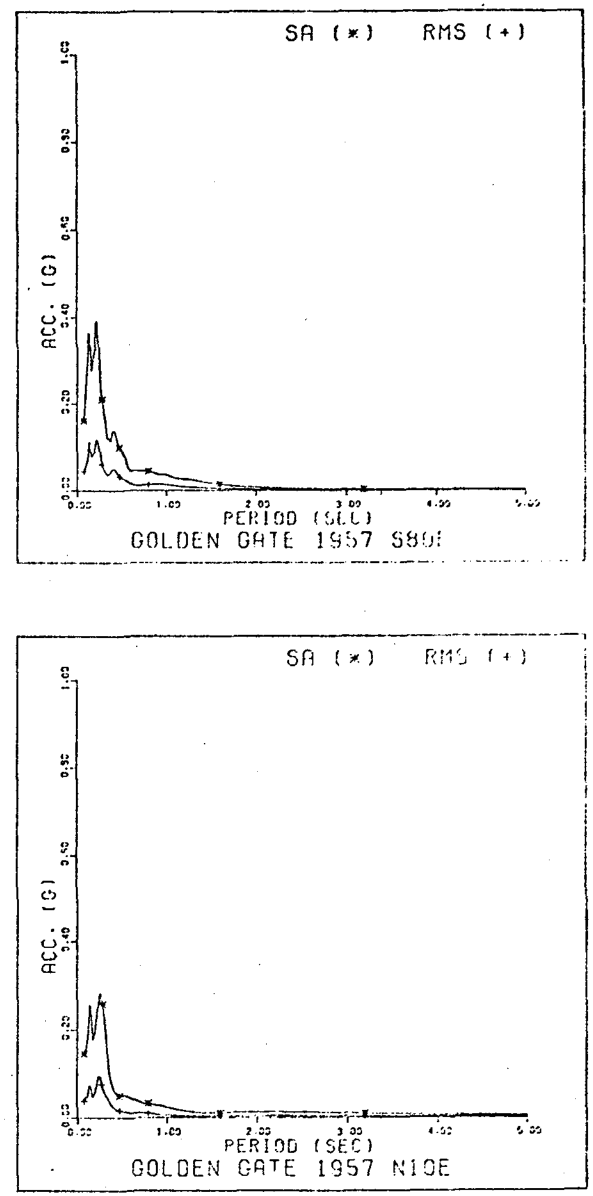


(A011) (A013)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

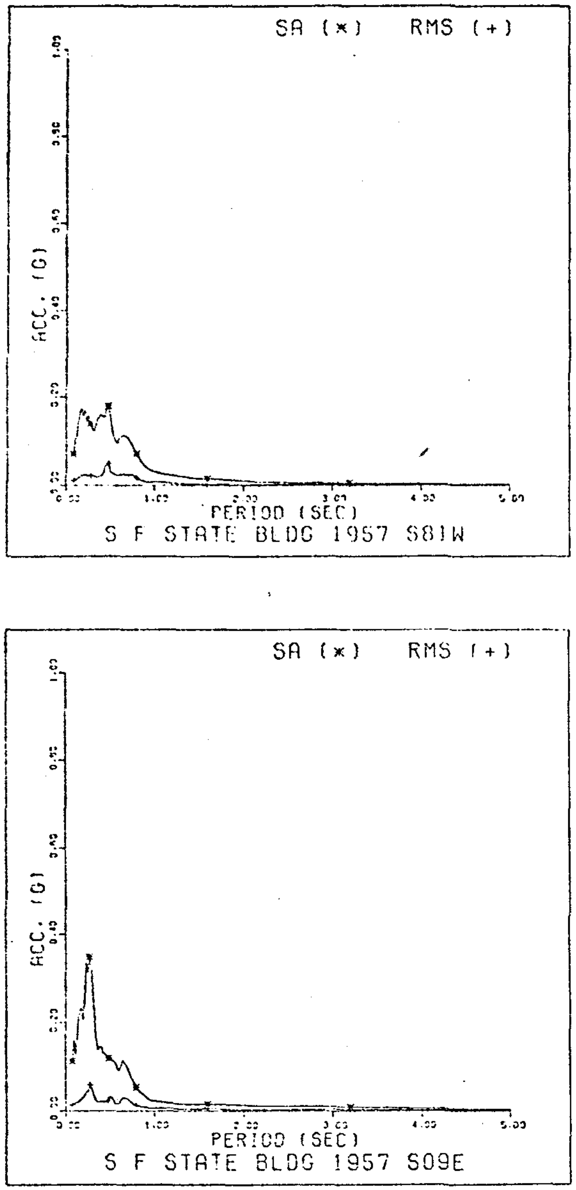


(A014)

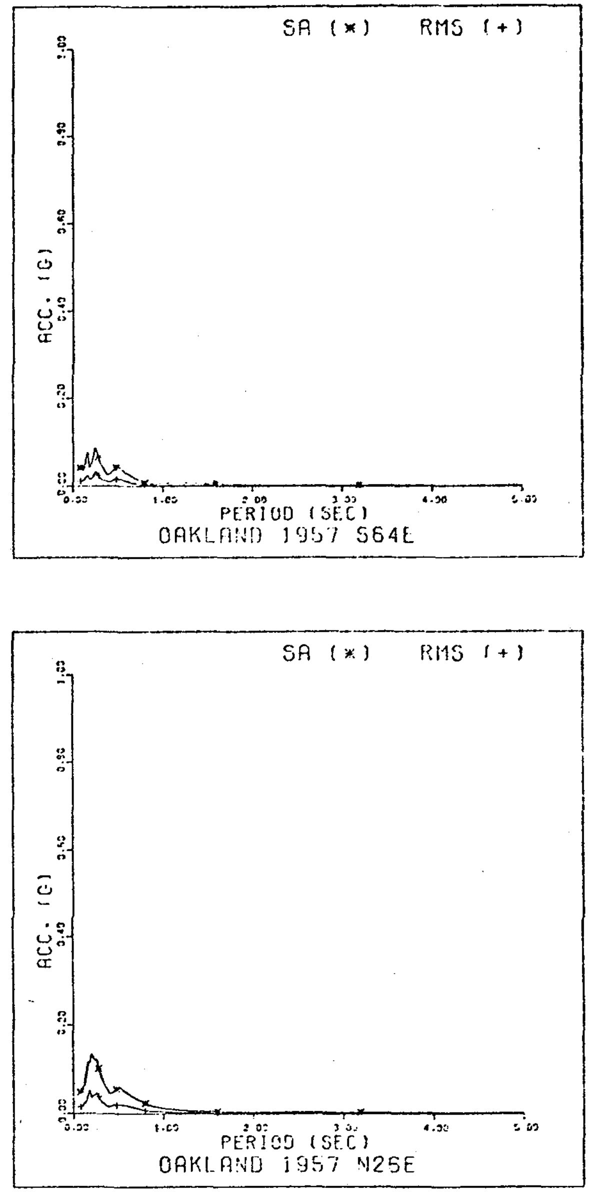


(A015)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

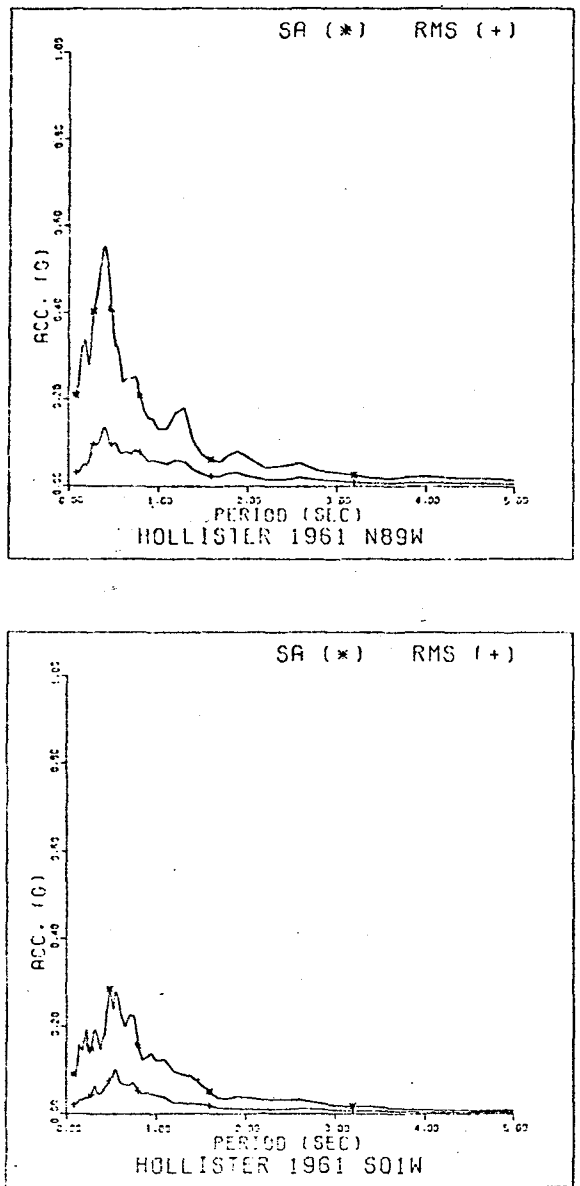


(A016)

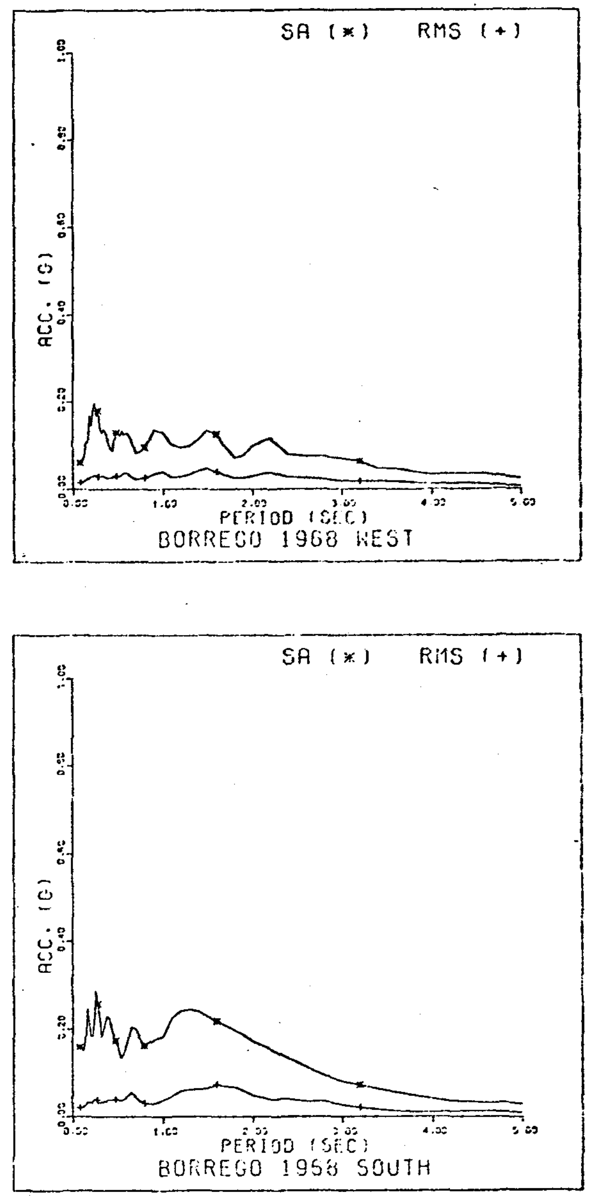


(A017)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

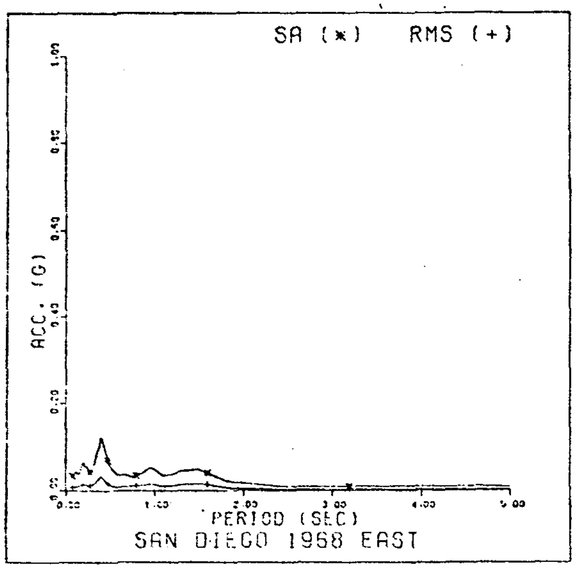


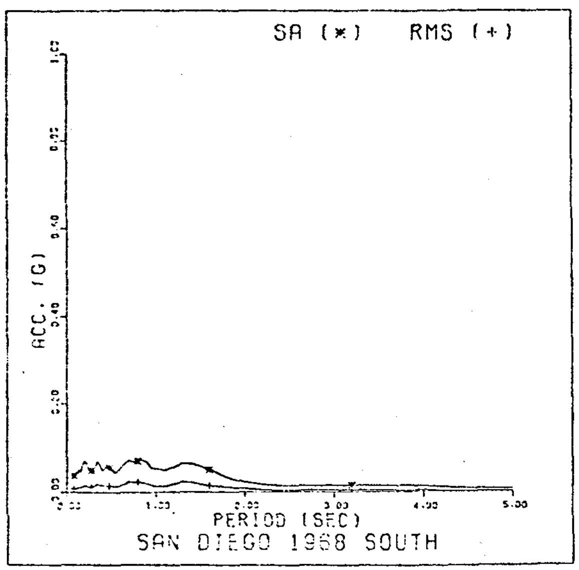
(A018)



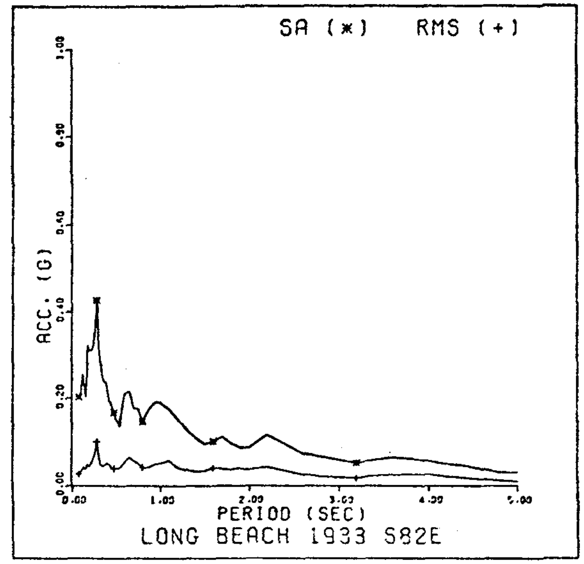
(A019)

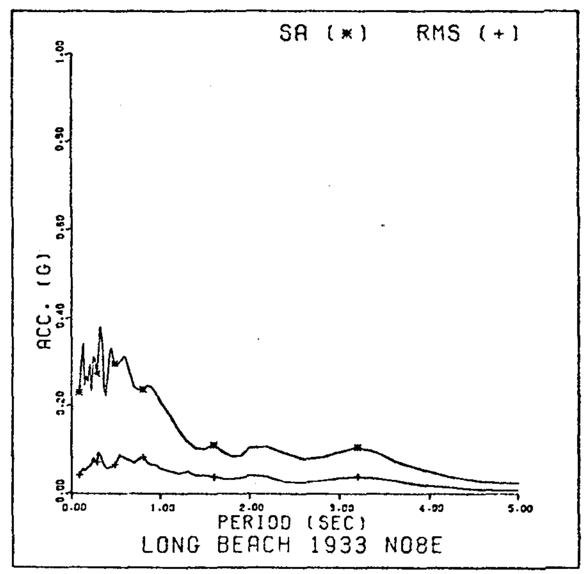
FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)





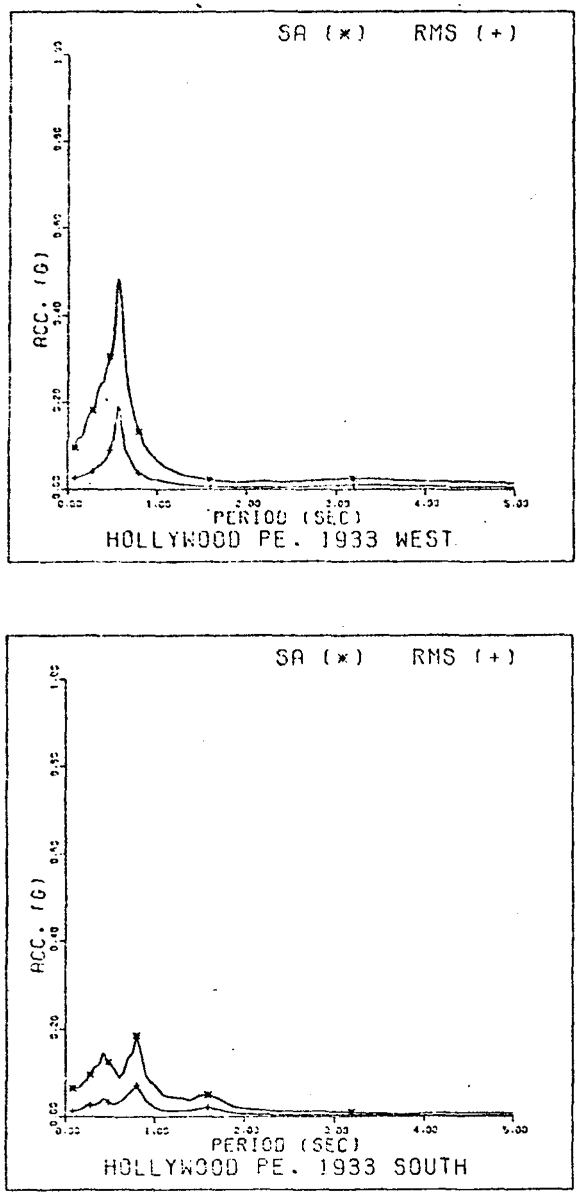
(A020)



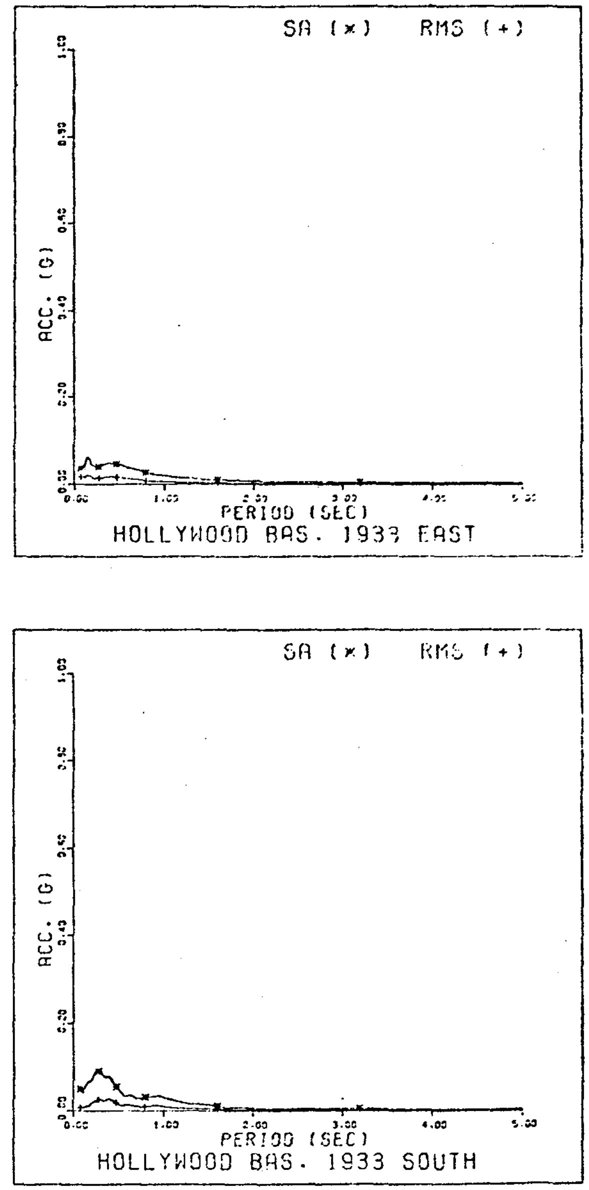


(B021)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

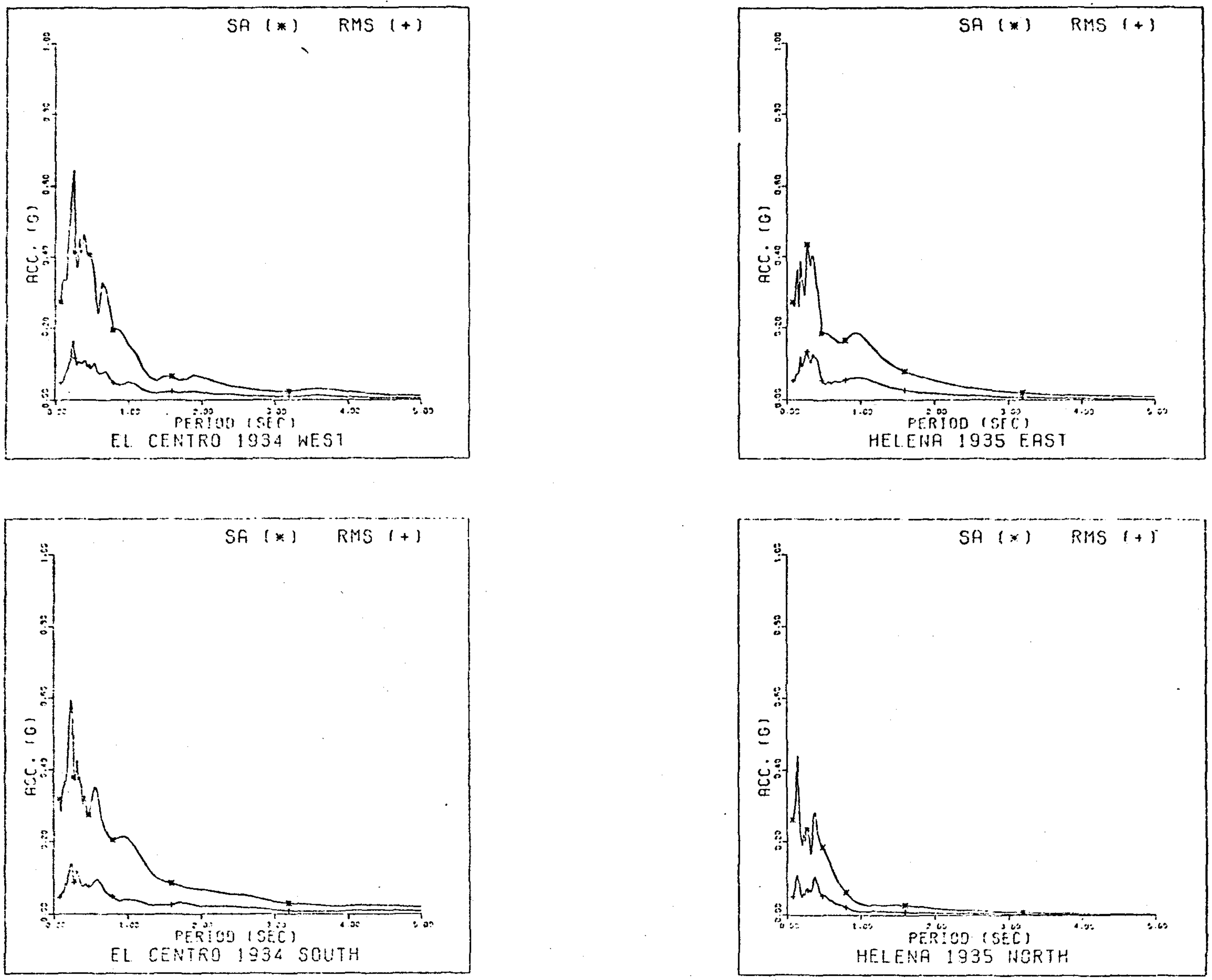


(B022)



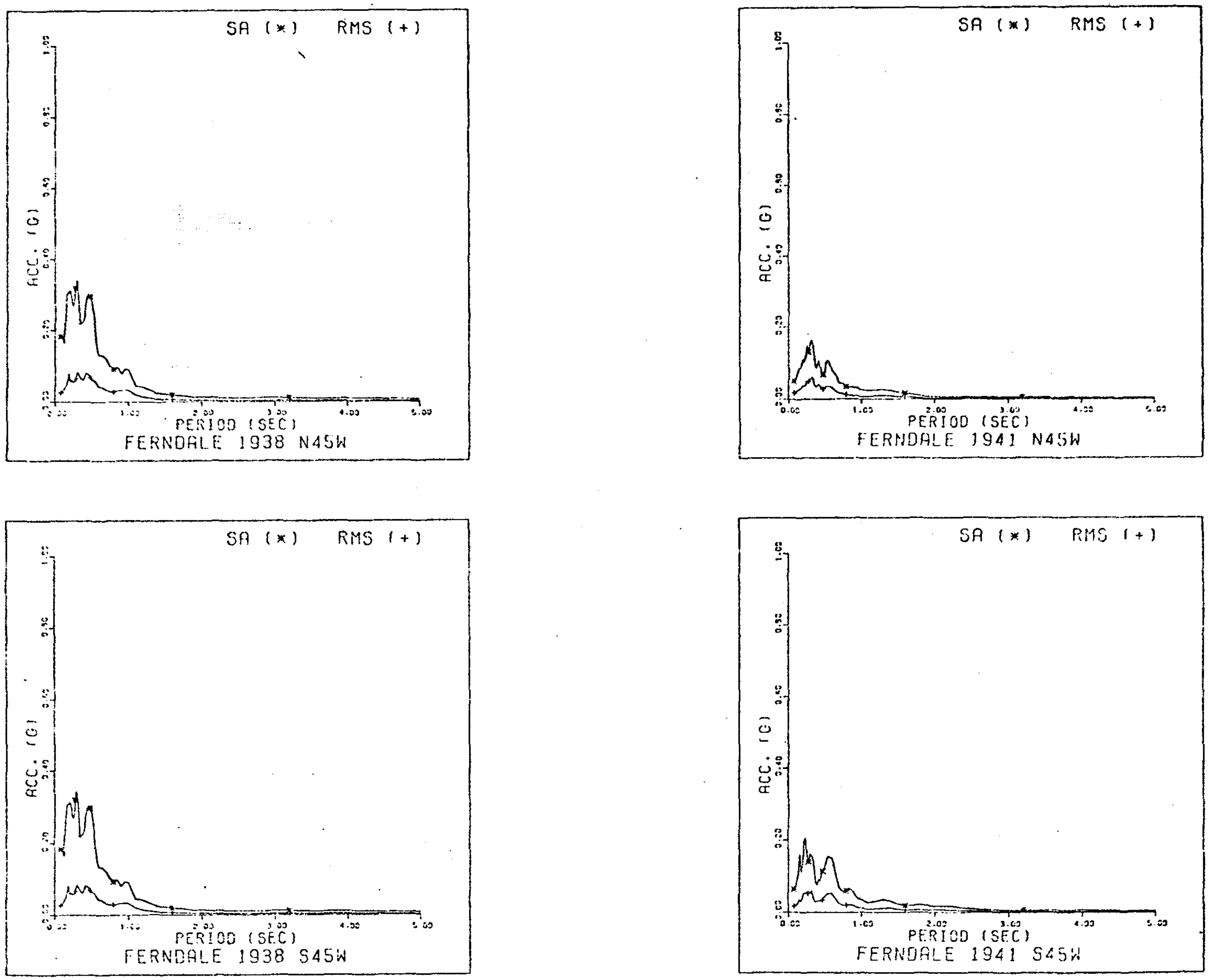
(B023)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)



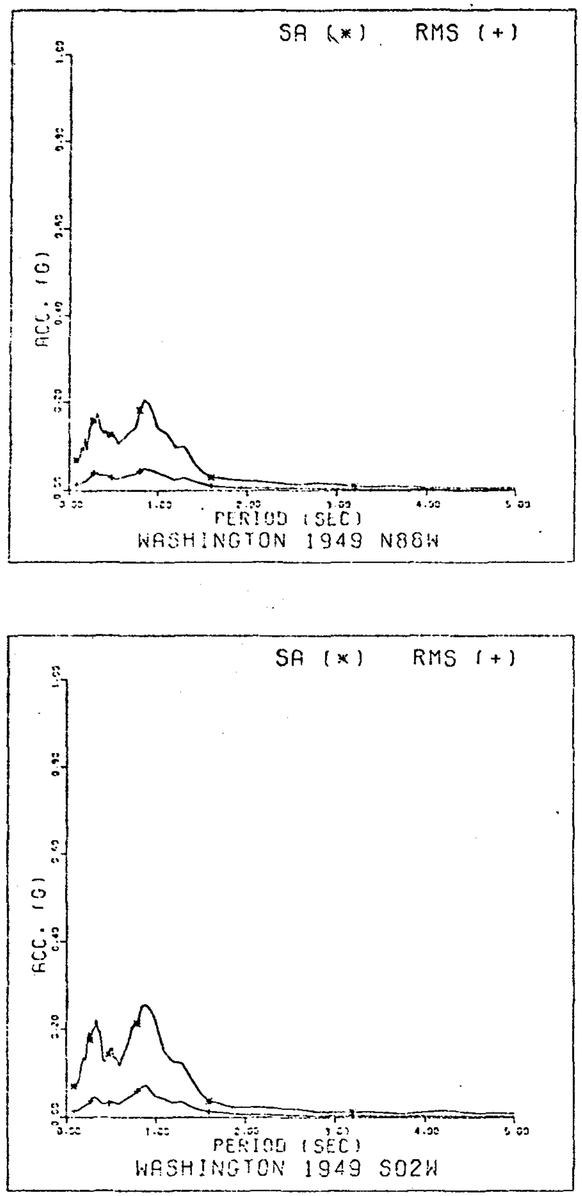
(B024) (B025)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

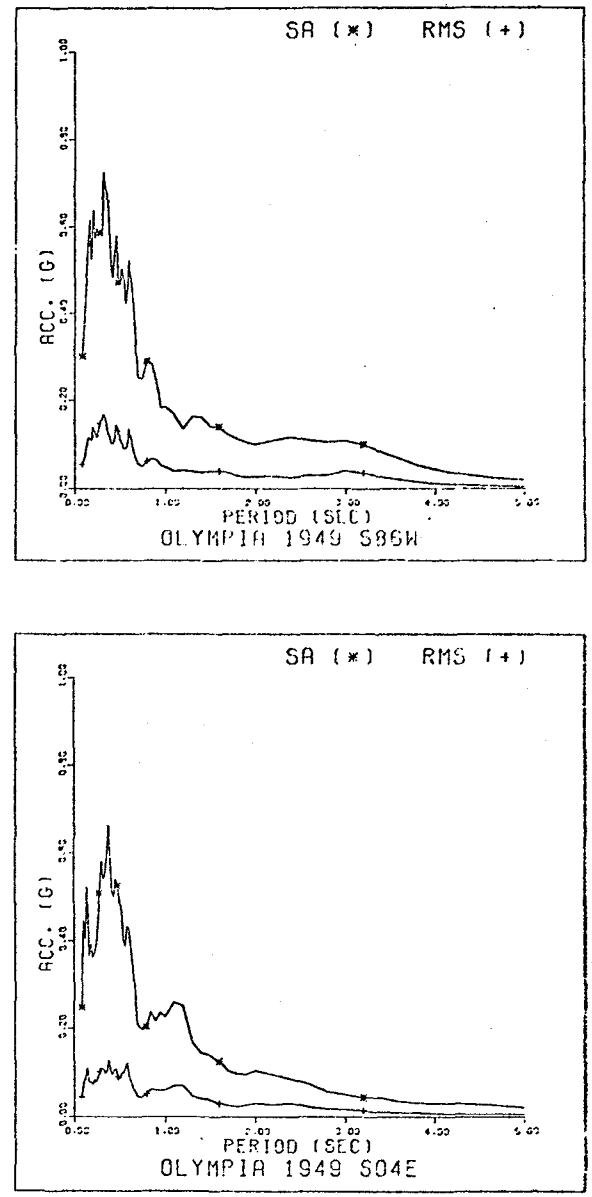


(B026) (B027)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

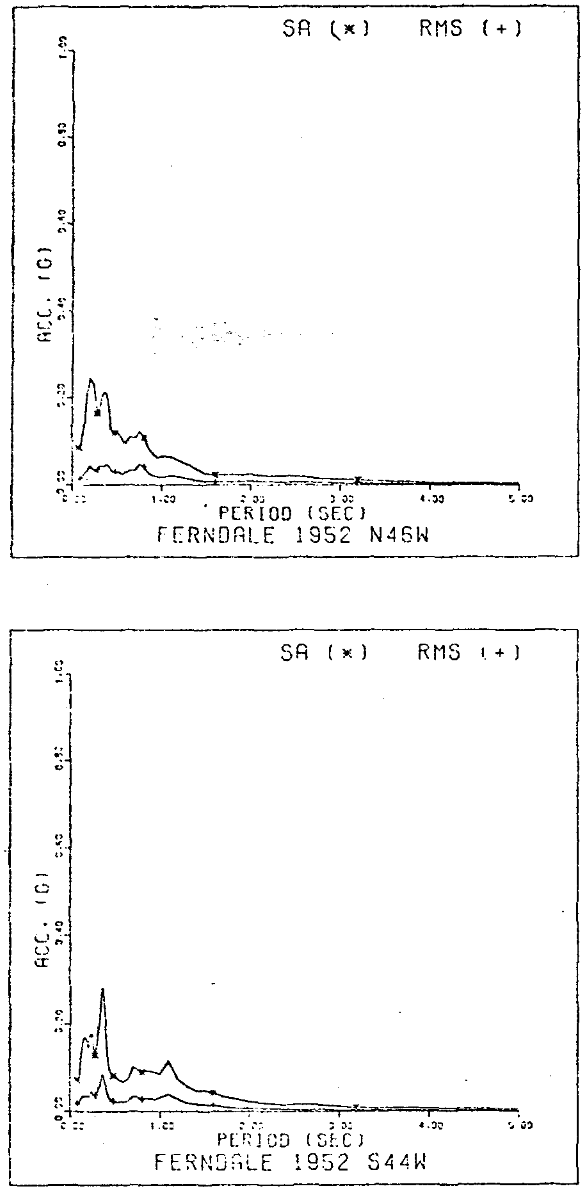


(B028)

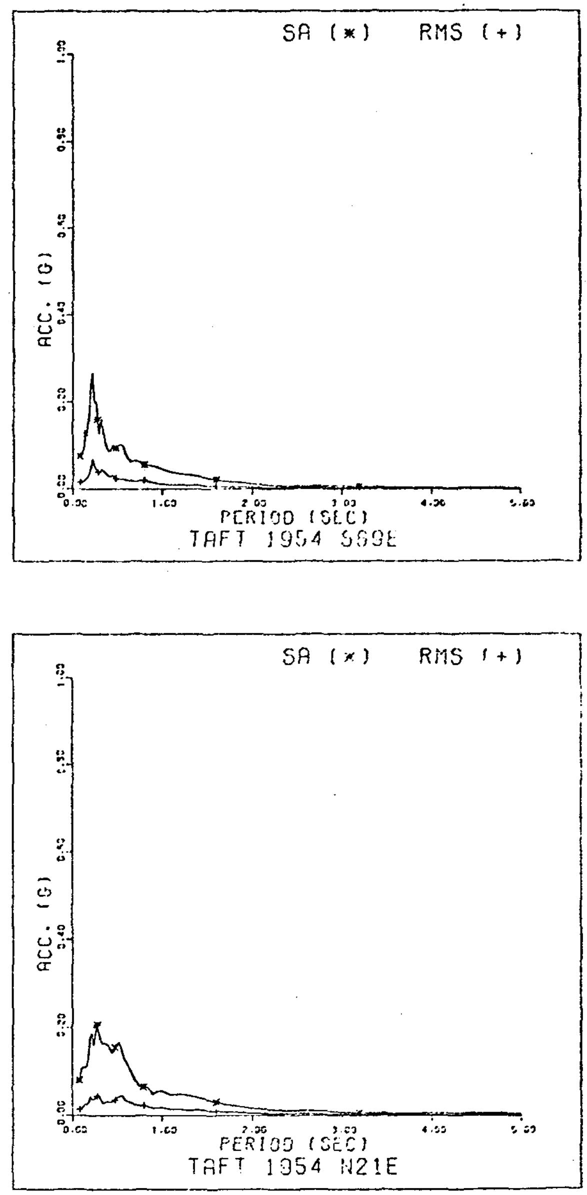


(B029)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

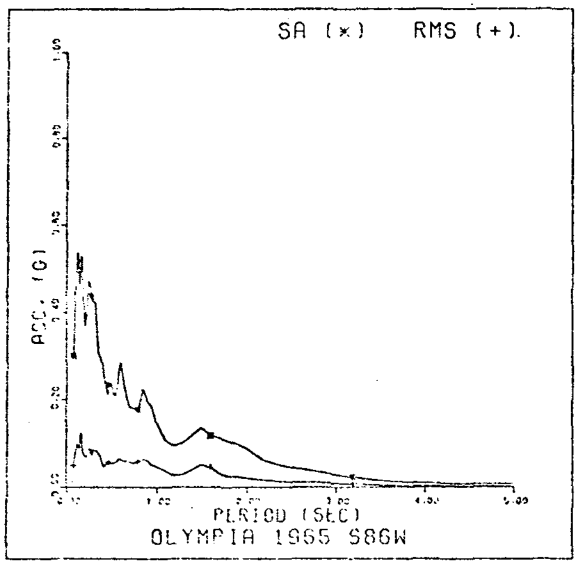


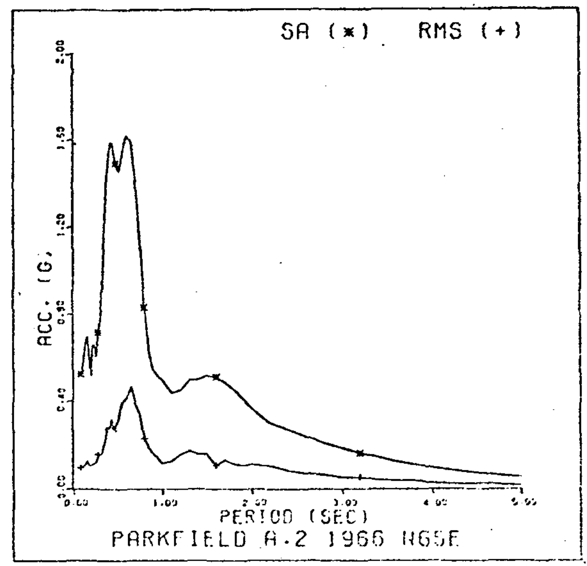
(B030)



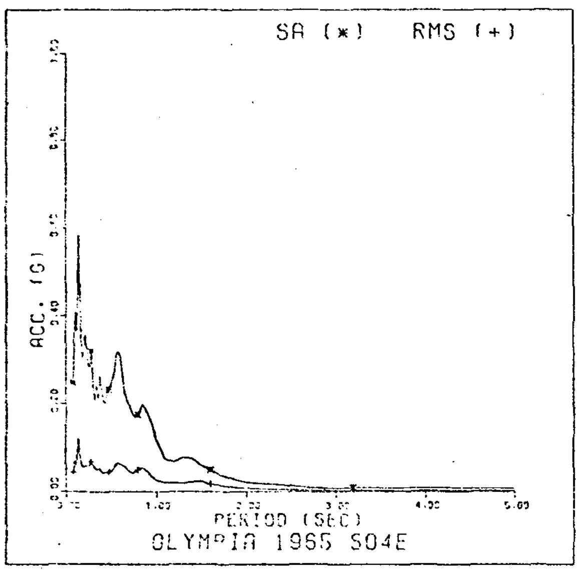
(B031)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)



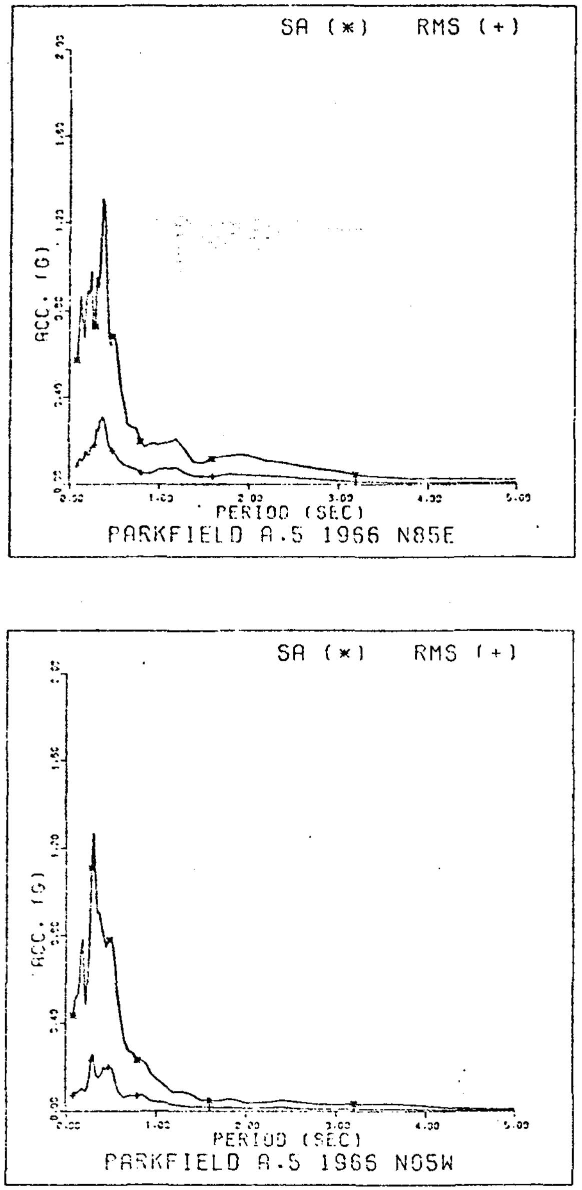


(B033)

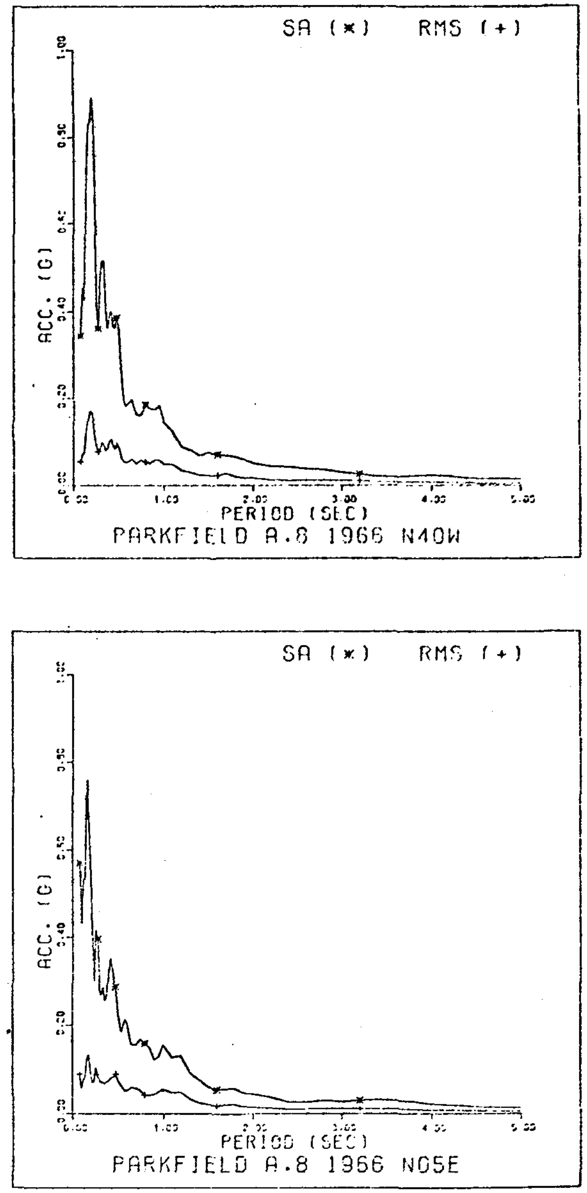


(B032)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

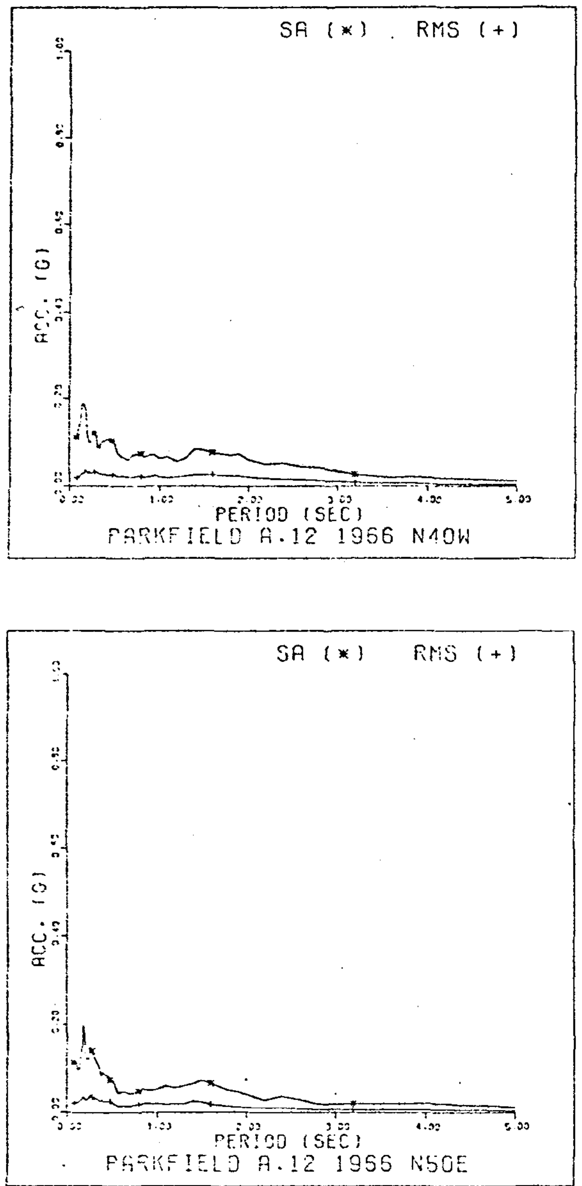


(B034)

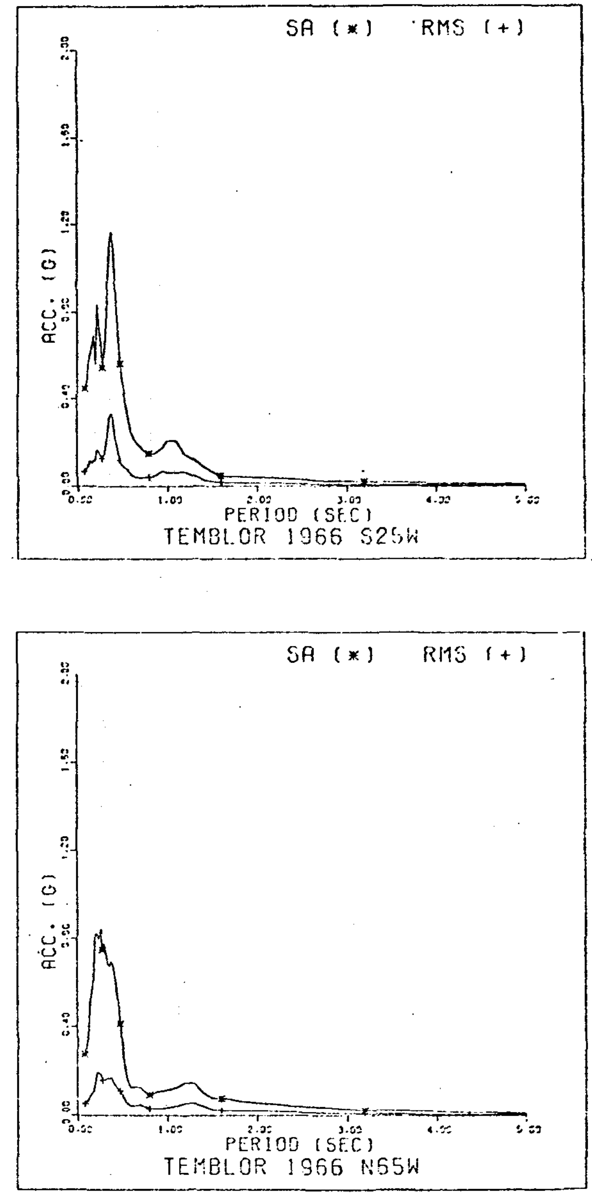


(B035)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

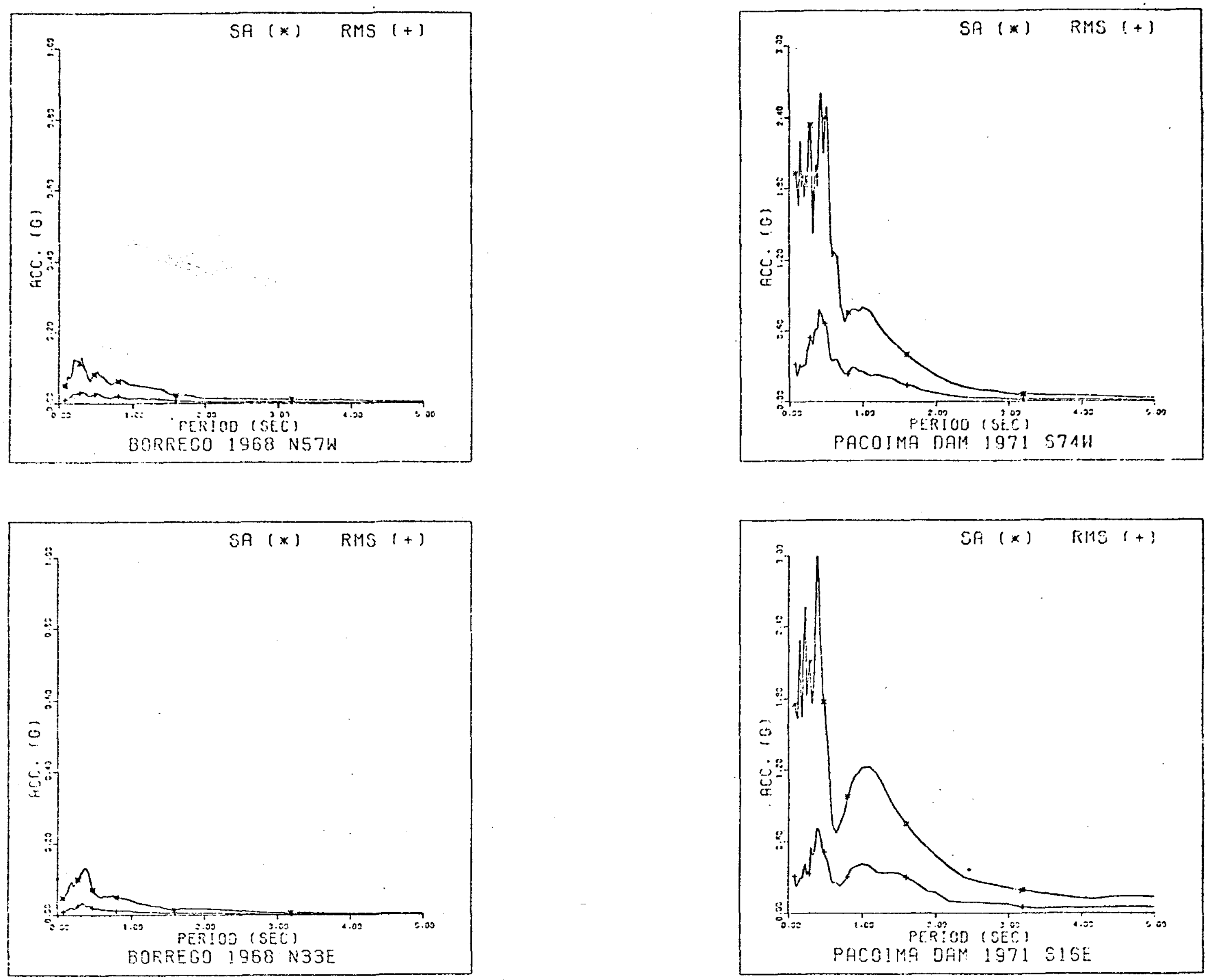


(B036)



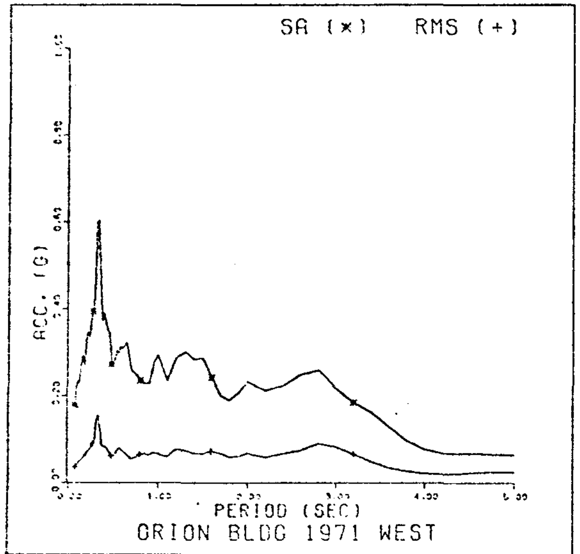
(B037)

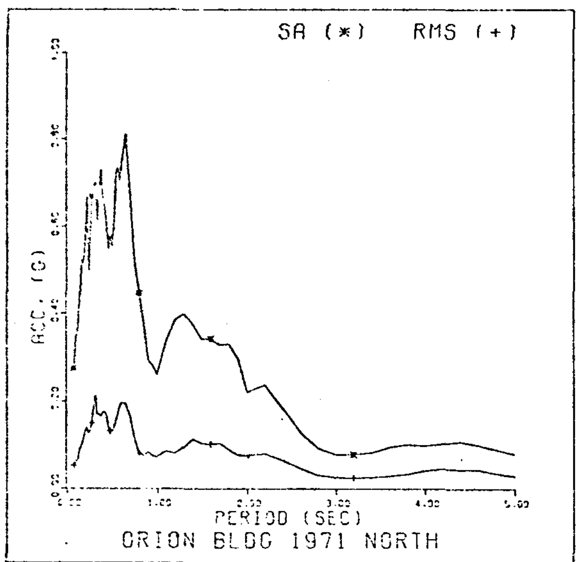
FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)



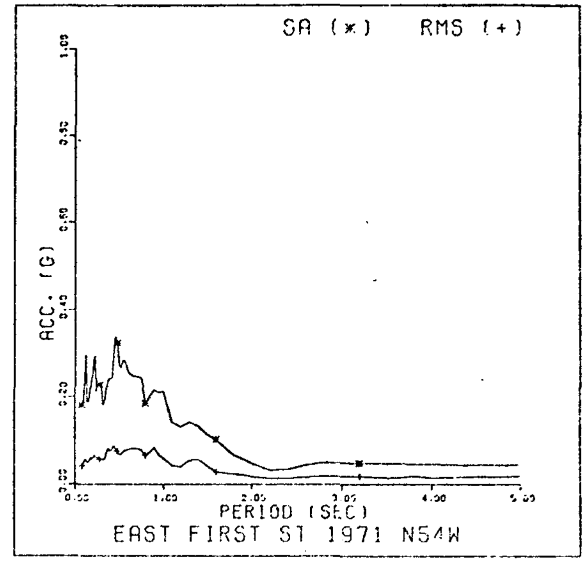
(B040) (C041)

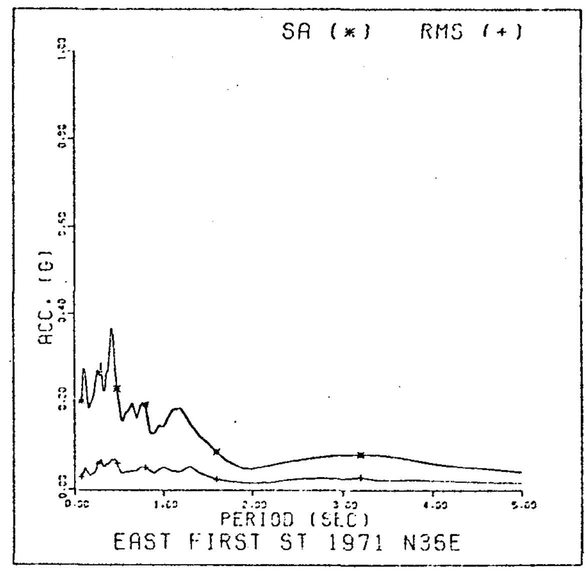
FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)





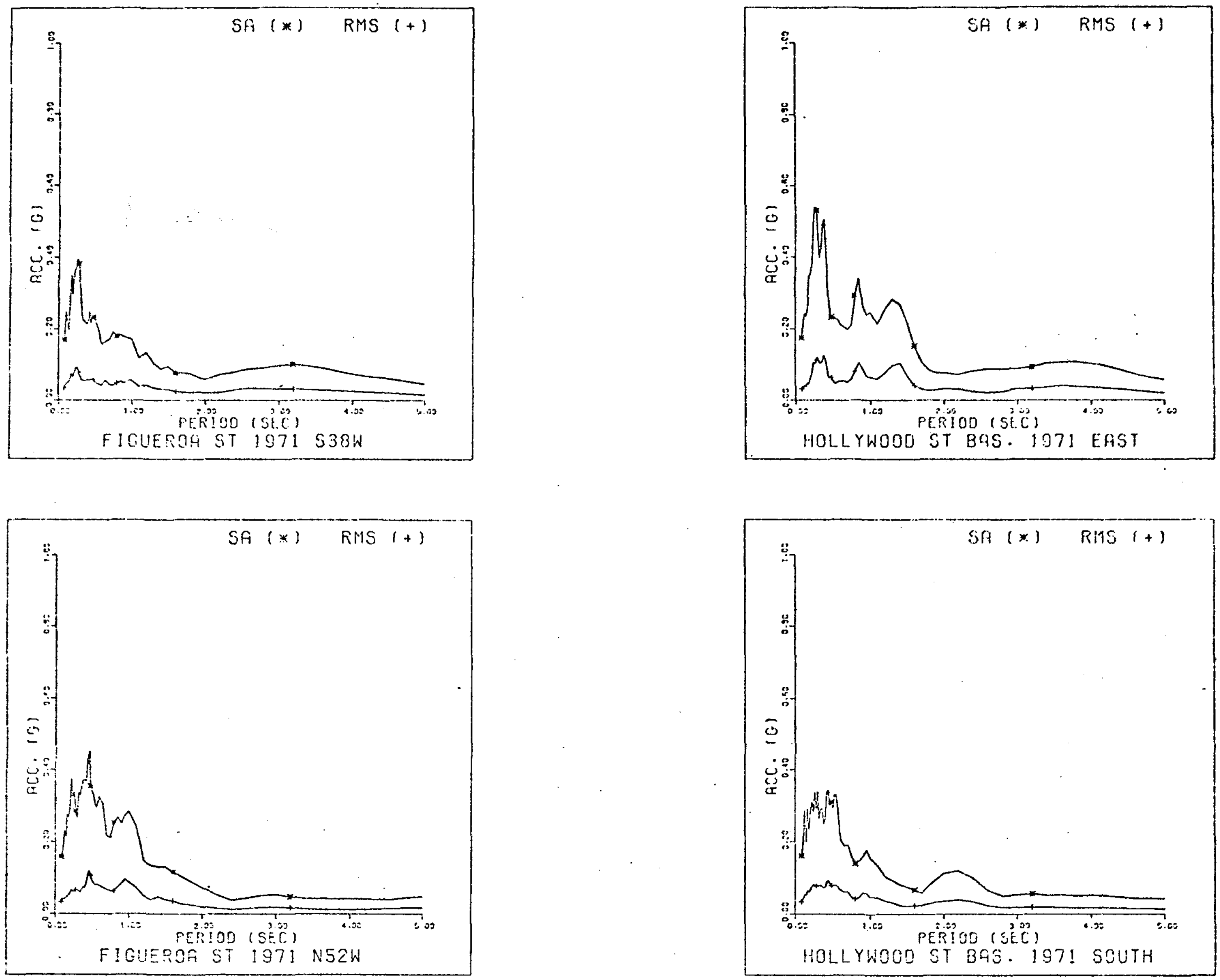
(C048)





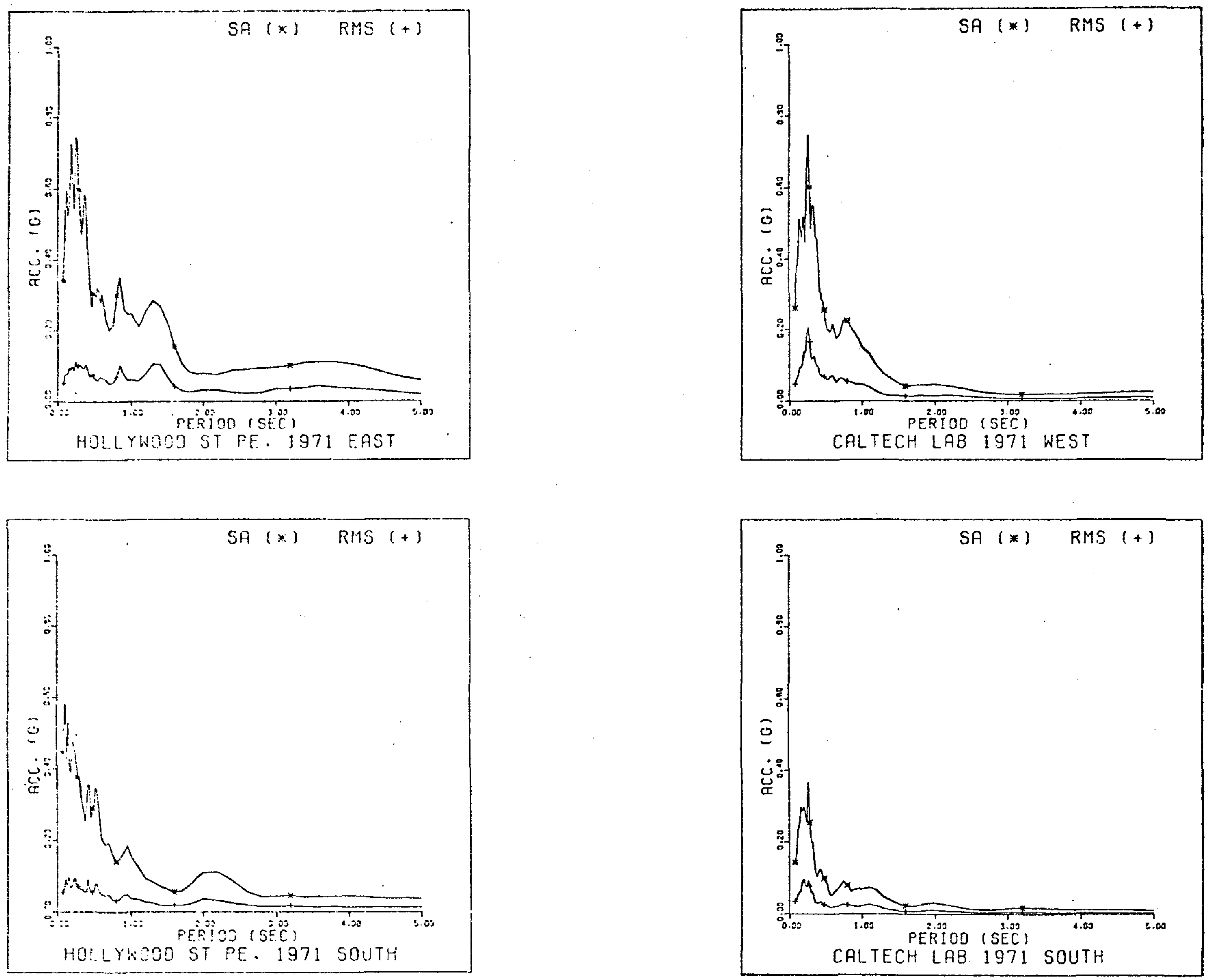
(C051)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)



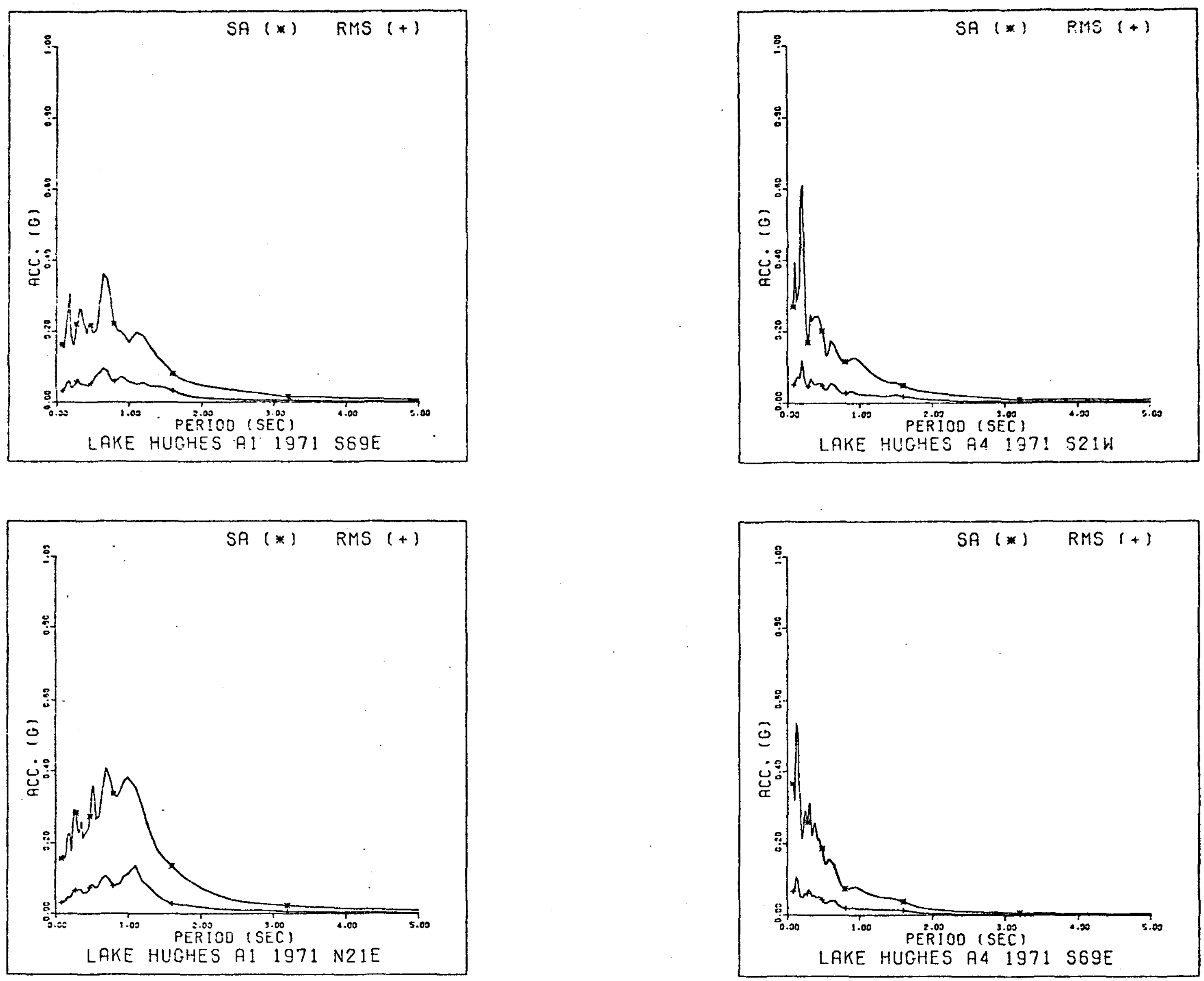
(C054) (D057)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)



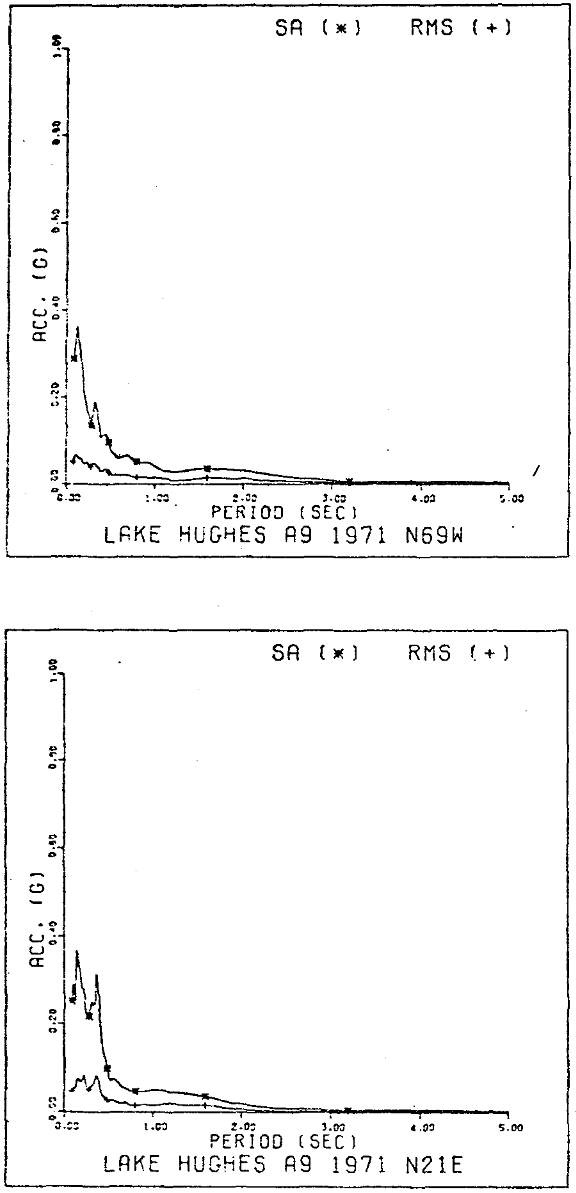
(D058) (G106)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

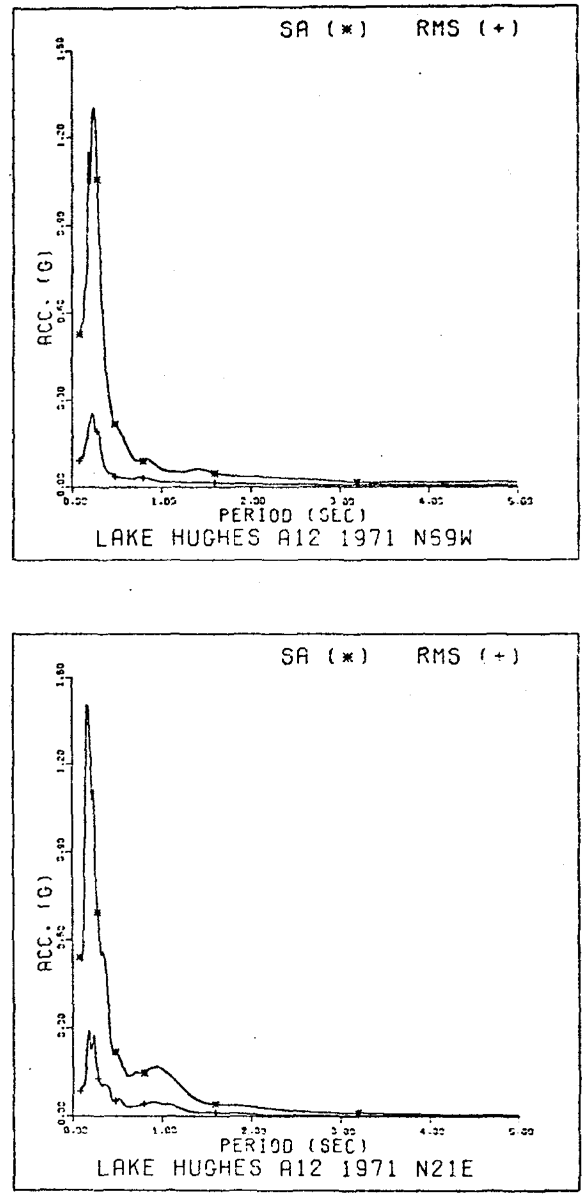


(J141) (J142)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

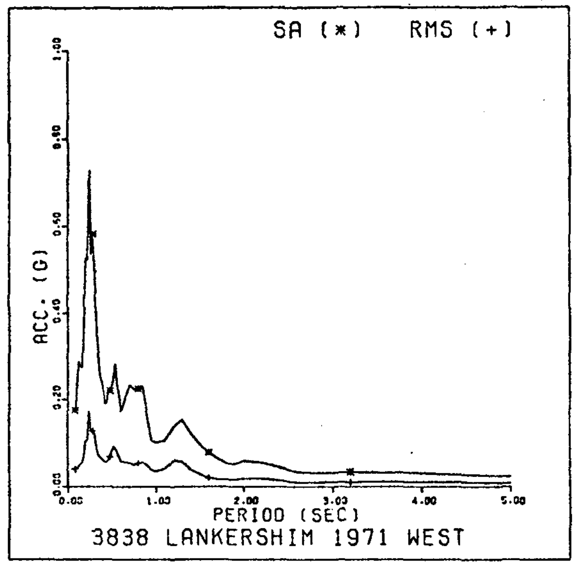


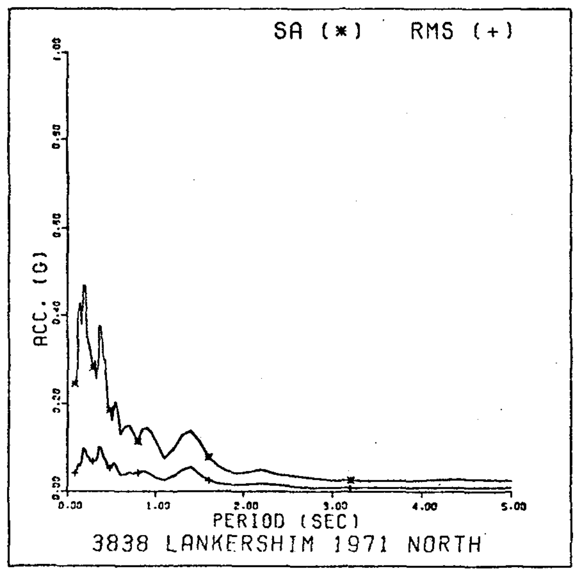
(J143)



(J144)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)





(L166)

FIGURE 4.4. Acceleration and RMS Response Spectra (Cont.)

the exponential distribution is used in this study. The probability distribution function for exponential shape is given by

$$f_A(a) = \lambda e^{-\lambda a} \tag{4.5}$$

where A = random variable defining the acceleration amplitude

a = the values A takes

λ = constant of the exponential distribution

It should be pointed out that once the distribution of the amplitudes is known, any probability statement regarding the response acceleration can be made. As an example

$$P(\text{peak amplitude } A \geq a) = \int_a^\infty \lambda e^{-\lambda A} dA \tag{4.6}$$

$$= e^{-\lambda a}$$

This information is extensively used in determining a_p.

- Mean response acceleration (Column 6: λ)

  This parameter is the average of the acceleration throughout the record. It shows the same stability as the RMS. It is equal to $1/\lambda$ where λ is the parameter of the exponential distribution.

- a_p (Column 7: p = 5%; Column 8: = 10%)

  This variable represents the response acceleration which has a probability p of exceedence for a given acceleration response (Fig. 4.2).

- ENGY (Column 9)

  The cumulative potential energy stored at any time in the spring of the single degree of freedom system is computed for the duration of the response. Consider the single degree of freedom system shown in Figure 4.5. The motion of the support is known in terms of its acceleration $\ddot{x}_o$ (earthquake record) and the quantity of interest is the relative displacement $y = x_1 - x_o$ (Biggs, 1964). The total energy in the system is equal to the kinetic energy of the mass plus the potential energy stored in the spring. During a free motion of this system, the potential energy is at times stored in the spring. While this energy is stored, the kinetic energy of the vibrating mass decreases. Thus, when there is maximum potential energy in the spring, the kinetic energy of the mass is zero. Conversely, when the kinetic energy is maximum the potential energy in the spring

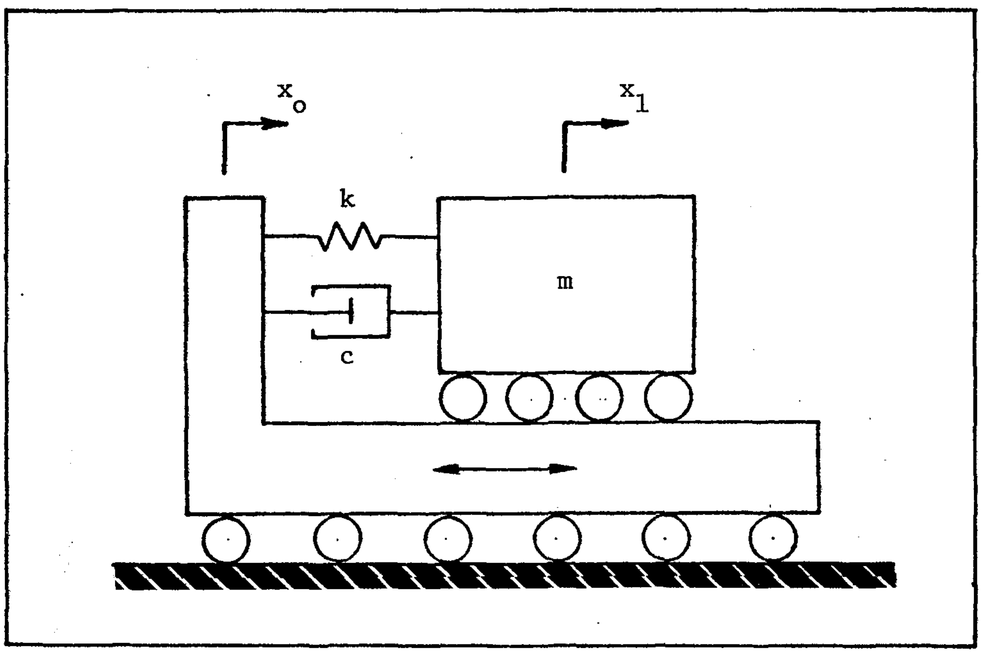


FIGURE 4.5. Single Degree of Freedom System. Mass m Elastically Supported from a Moving Foundation with Viscous Damping

is zero. At any time one could calculate the kinetic energy of the mass and the potential energy in the spring. In addition to the above energy transfer, for a forced vibration (earthquake motion), there is a continuous addition of energy from the ground to the vibratory system. In this process, part of the energy is dissipated in the dashpot. The amount of dissipation is a function of the damping of the system. For any time increment Δt the energy per unit mass stored in the spring is equal to the relative displacement (Δy) multiplied by the absolute acceleration felt in the spring ($\ddot{x}_1$). The cumulative potential energy per unit mass (ENGY) stored in the spring is therefore

$$\mathrm{ENGY} = \sum_{\text{all } \Delta t} \Delta y \cdot \ddot{x}_1 \quad , \qquad \text{for } \Delta y \cdot \ddot{x}_1 > 0 \tag{4.7}$$

It seems that this parameter should be highly correlated to the damage of the vibratory system. It is also reasonable to assume that a design based on energy criteria is more rational than the current peak amplitude based procedure. The energy parameter is based explicitly on the acceleration level at each time increment and also on the duration of the duration of the response.

- Ratio $K_1 = a_p/\mathrm{RMS}$ (Column 10: $p = 5\%$; Column 11: $p = 10\%$)
  This ratio is one of the parameters investigated in this study for stable behavior. It can be seen that for all the records that are analyzed, its value is almost constant.

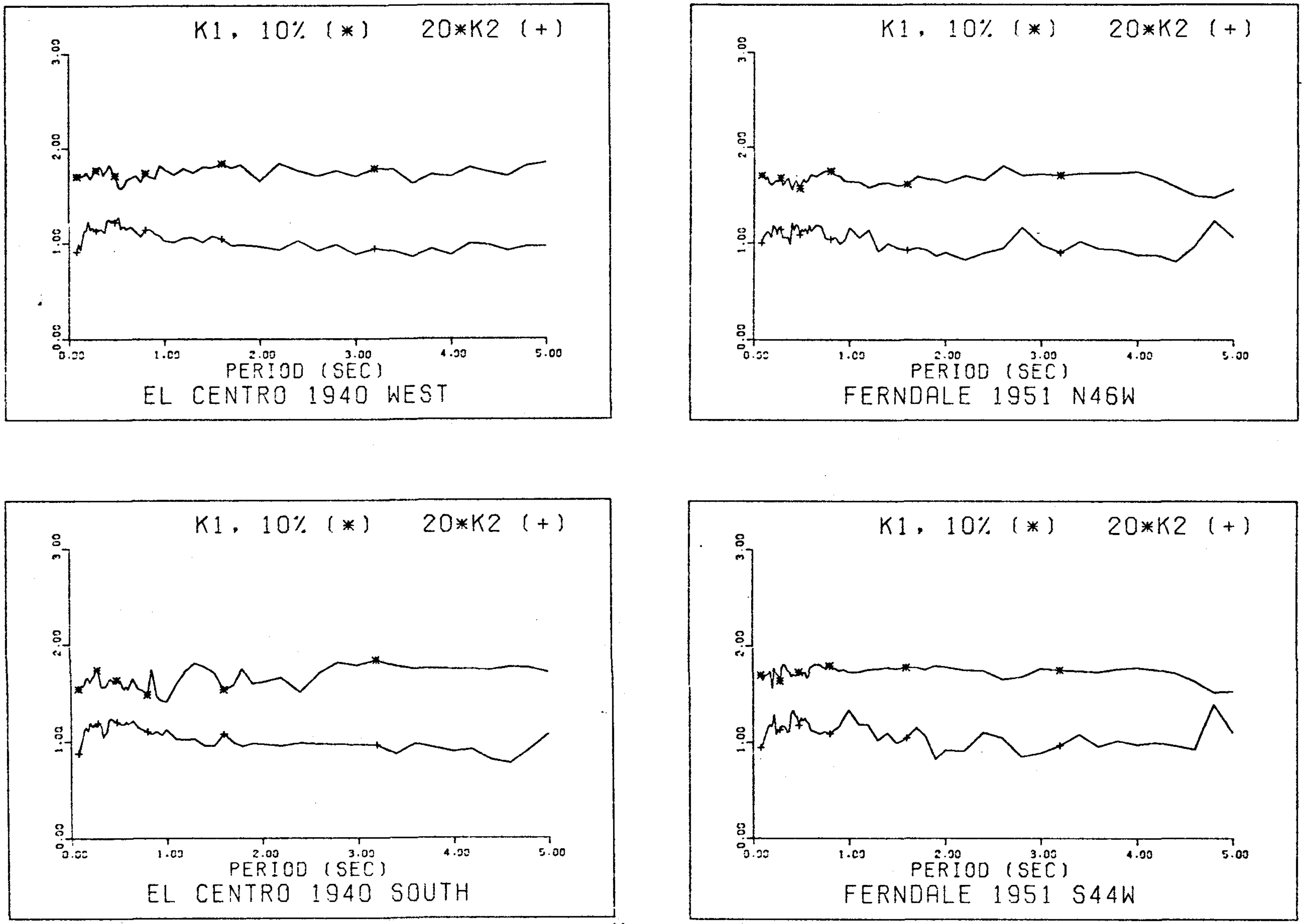
Further discussions on this parameter are presented in Chapter V.

- Ratio $K_2 = RMS^2 \cdot T^2/(ENGY/NBPK)$ (Column 12)

  Again, the stable behavior of this parameter prompted this study to evaluate it for all the available earthquake records. A detailed discussion will follow in Chapter V. Both parameters K_1 ($p = 10\%$) and K_2 are plotted in Fig. 4.6.

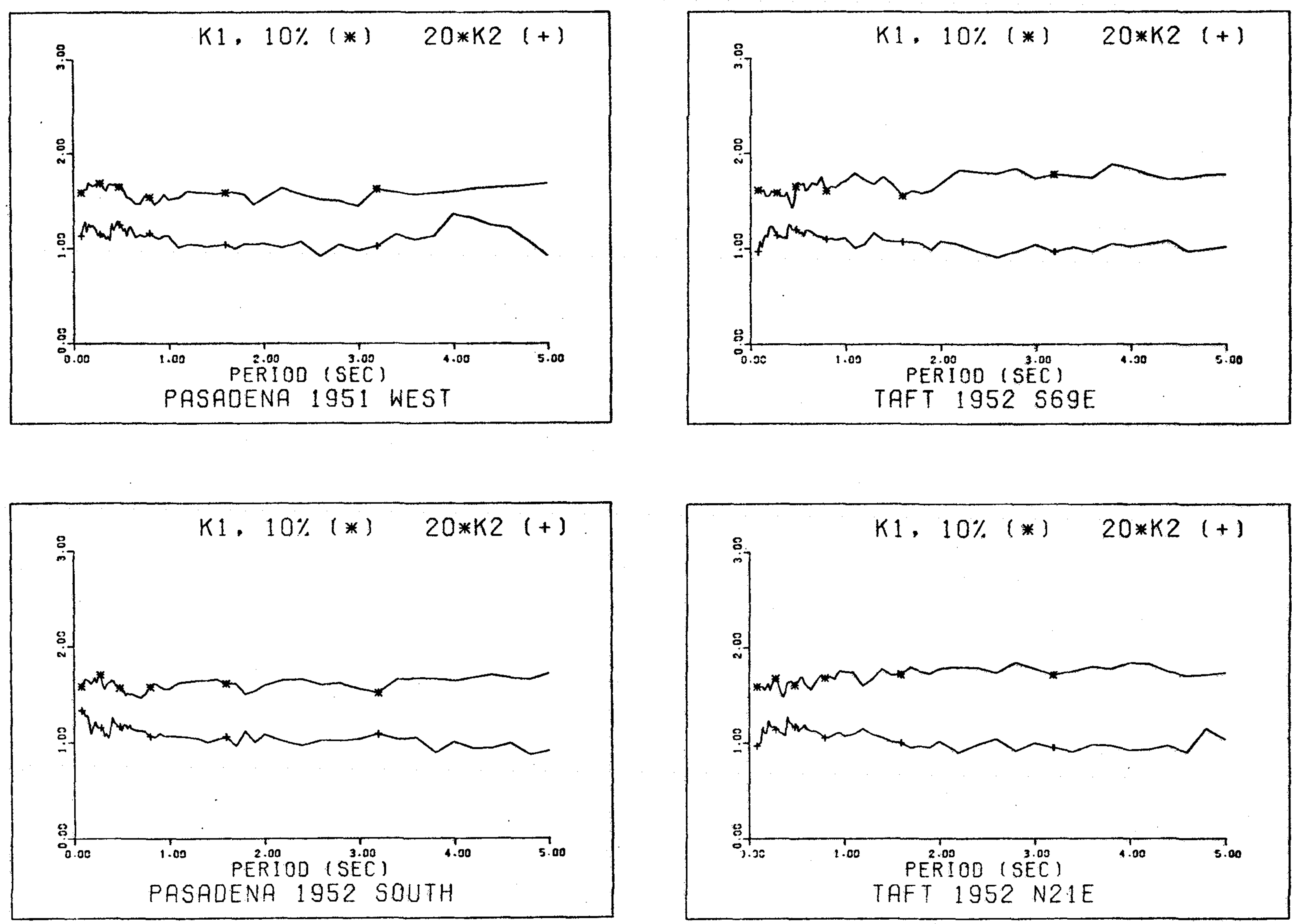
The reason for developing the parameters presented in Appendix B are:

- To numerically summarize the relevant parameters describing the response history
- To look at the behavior of the summary parameters for trends and similarities
- To obtain a stable input parameter which could be used for a better description of the response history.



(A001) (A002)

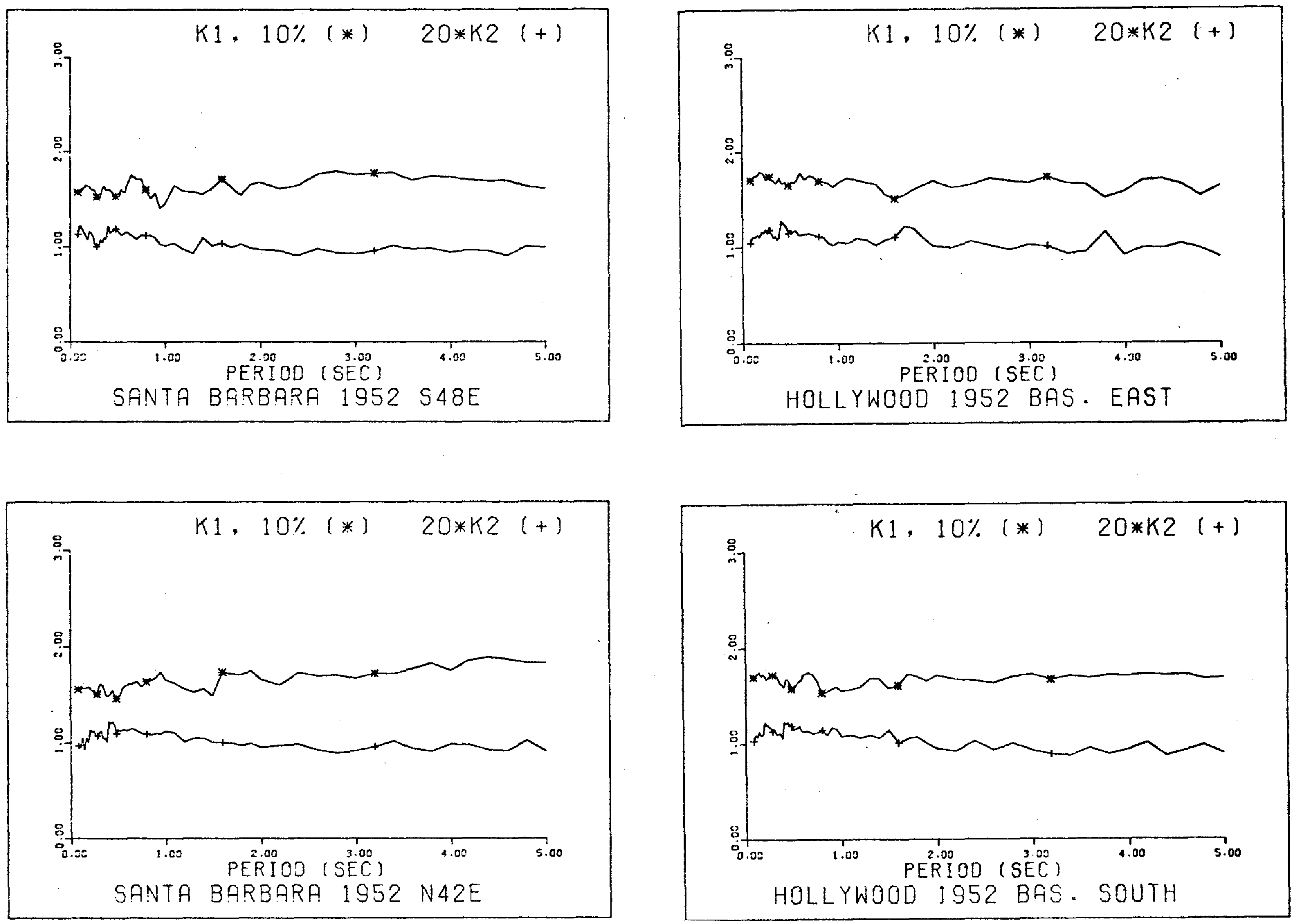
FIGURE 4.6. Factors K_1 and K_2



(A003)

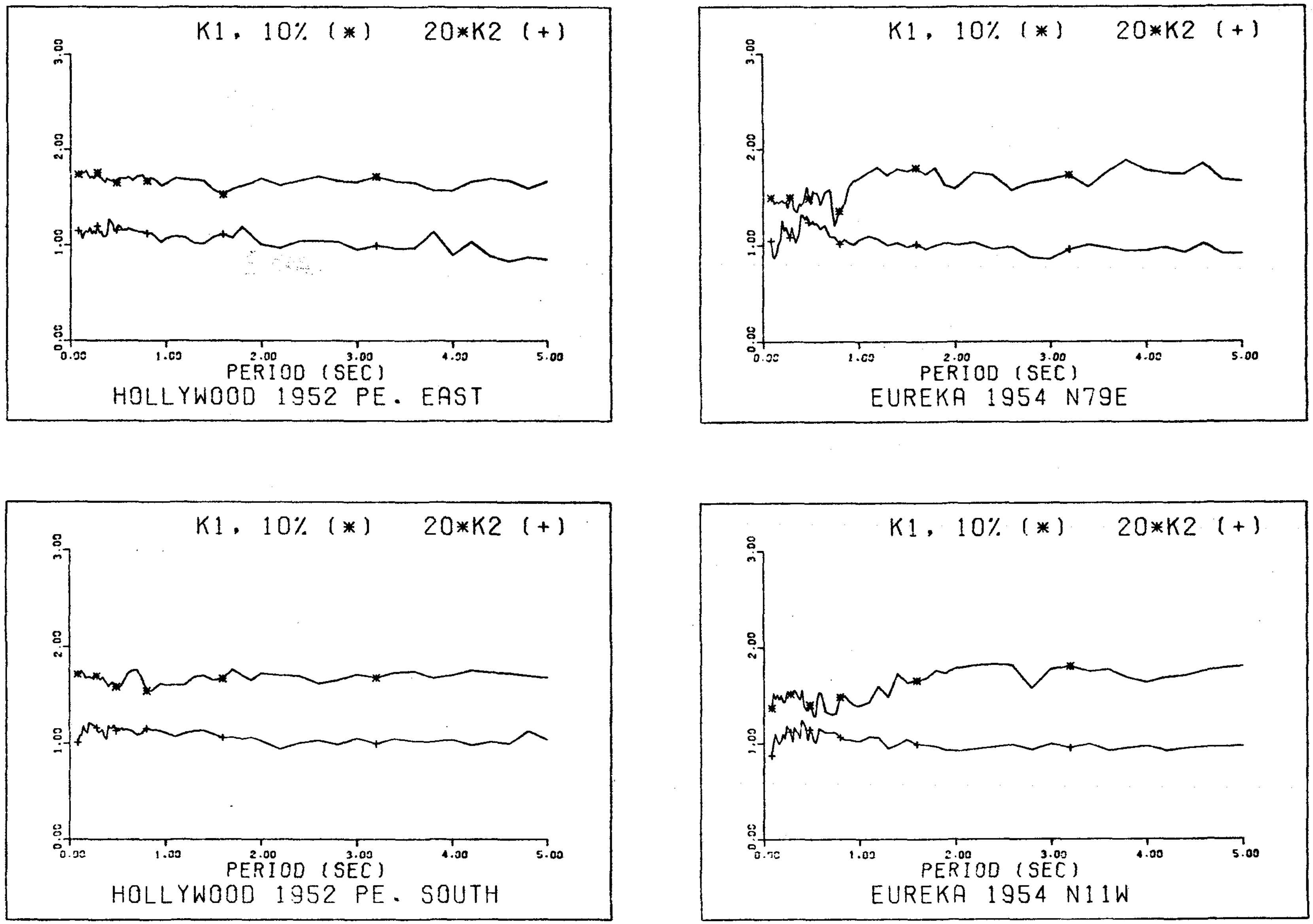
(A004)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



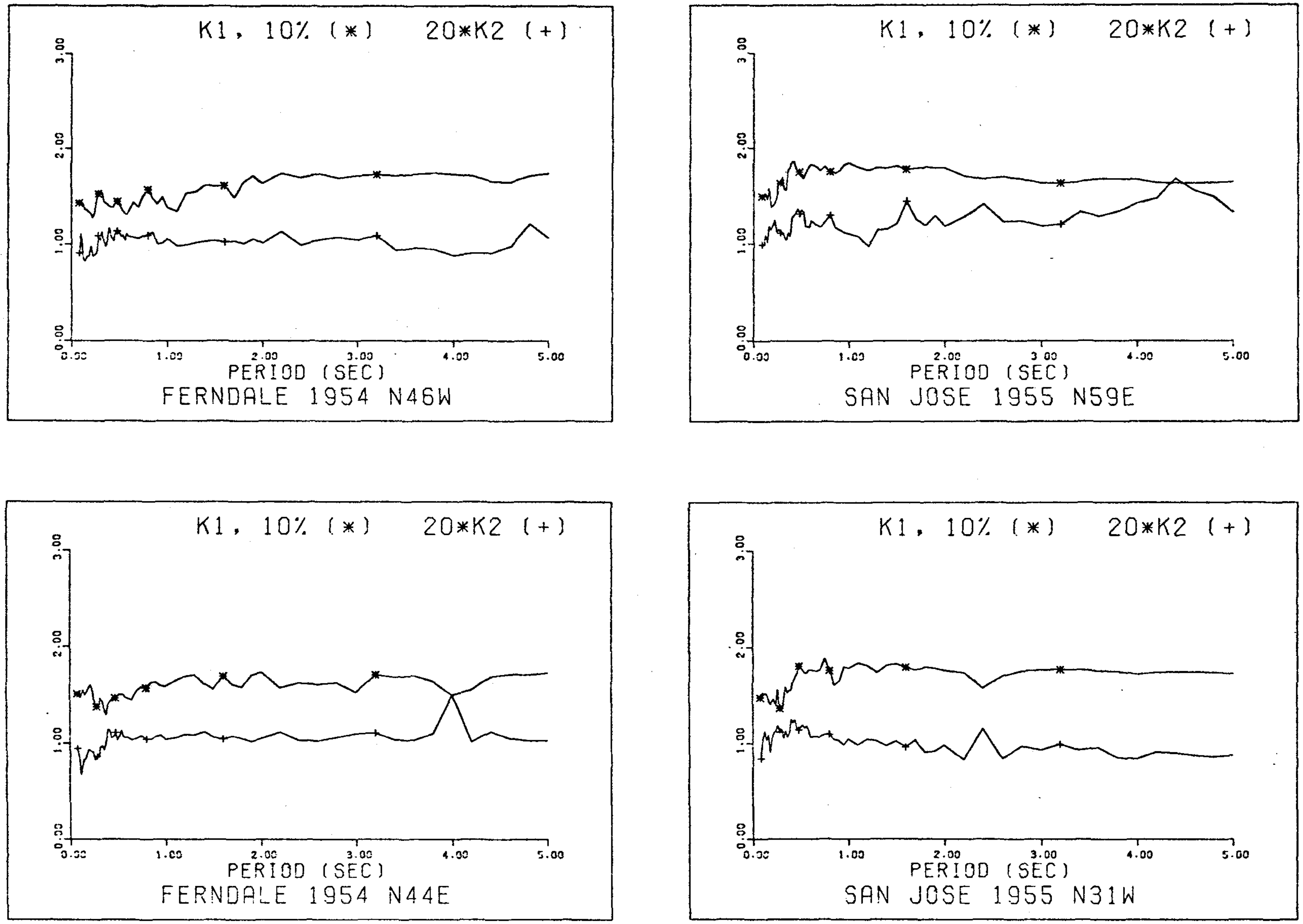
(A005) (A006)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



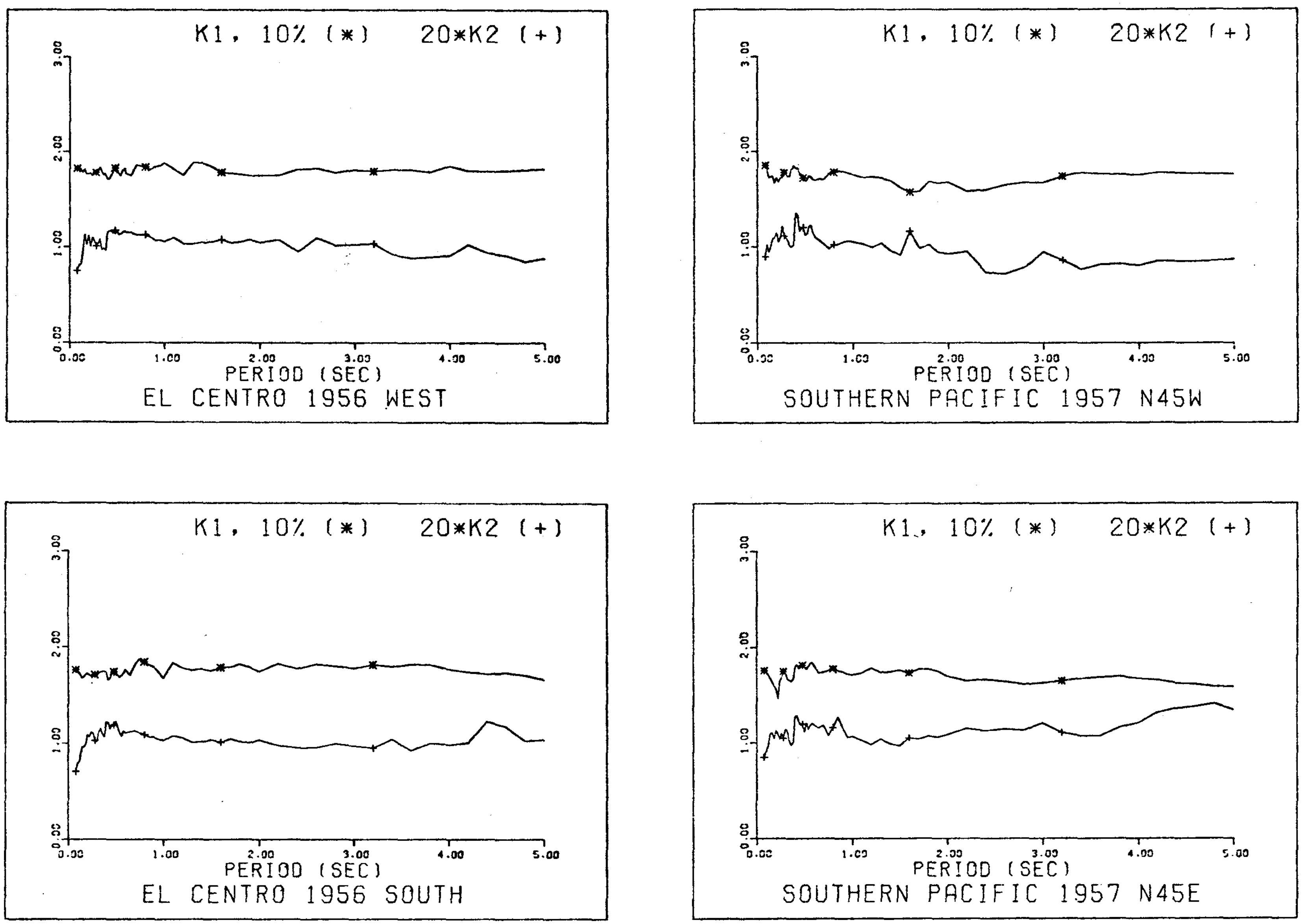
(A007) (A008)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



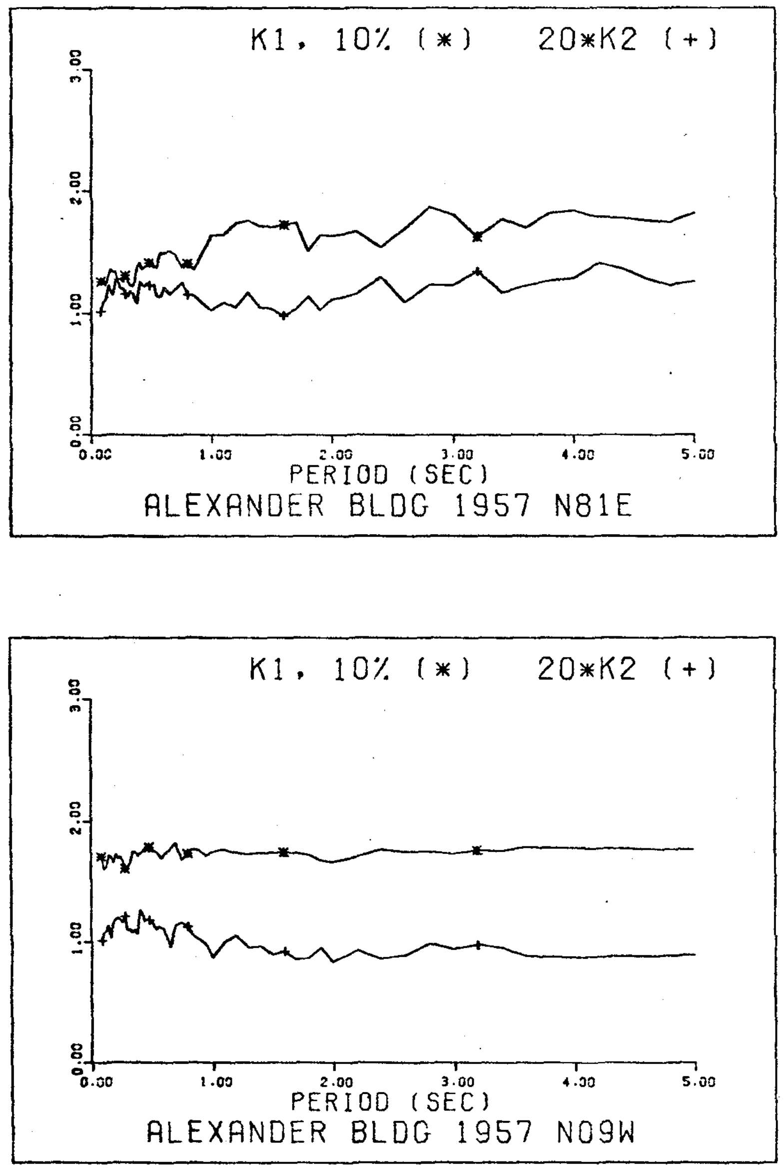
(A009) (A010)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)

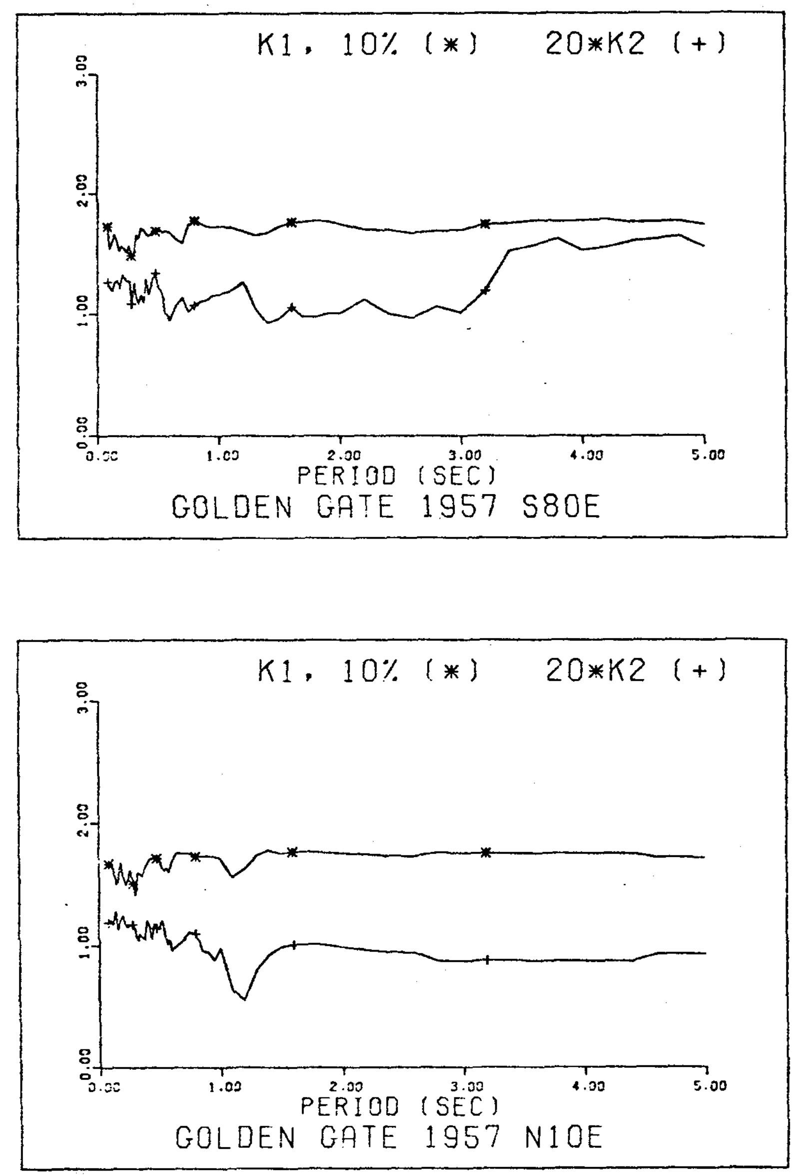


(A011) (A013)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)

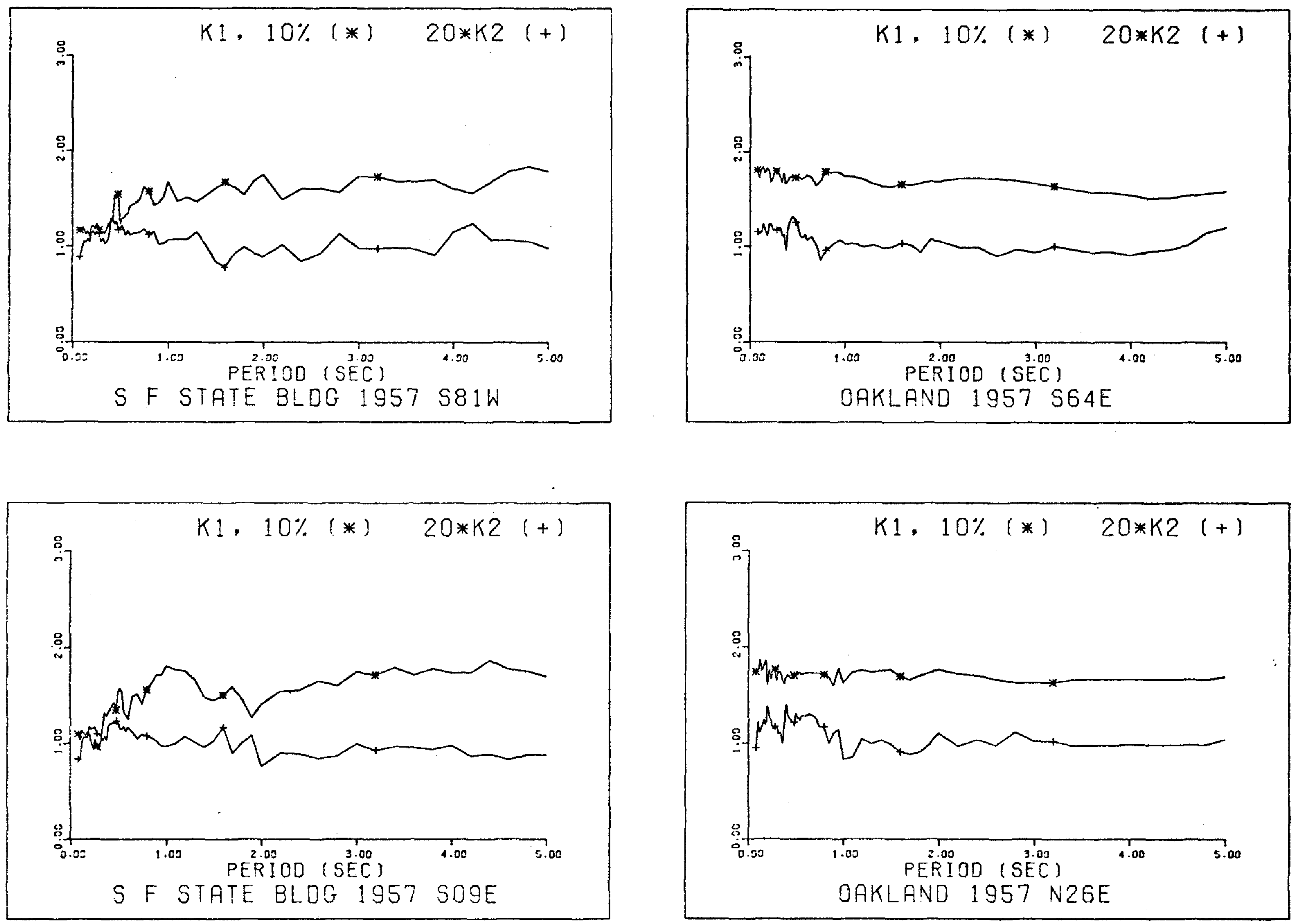


(A014)



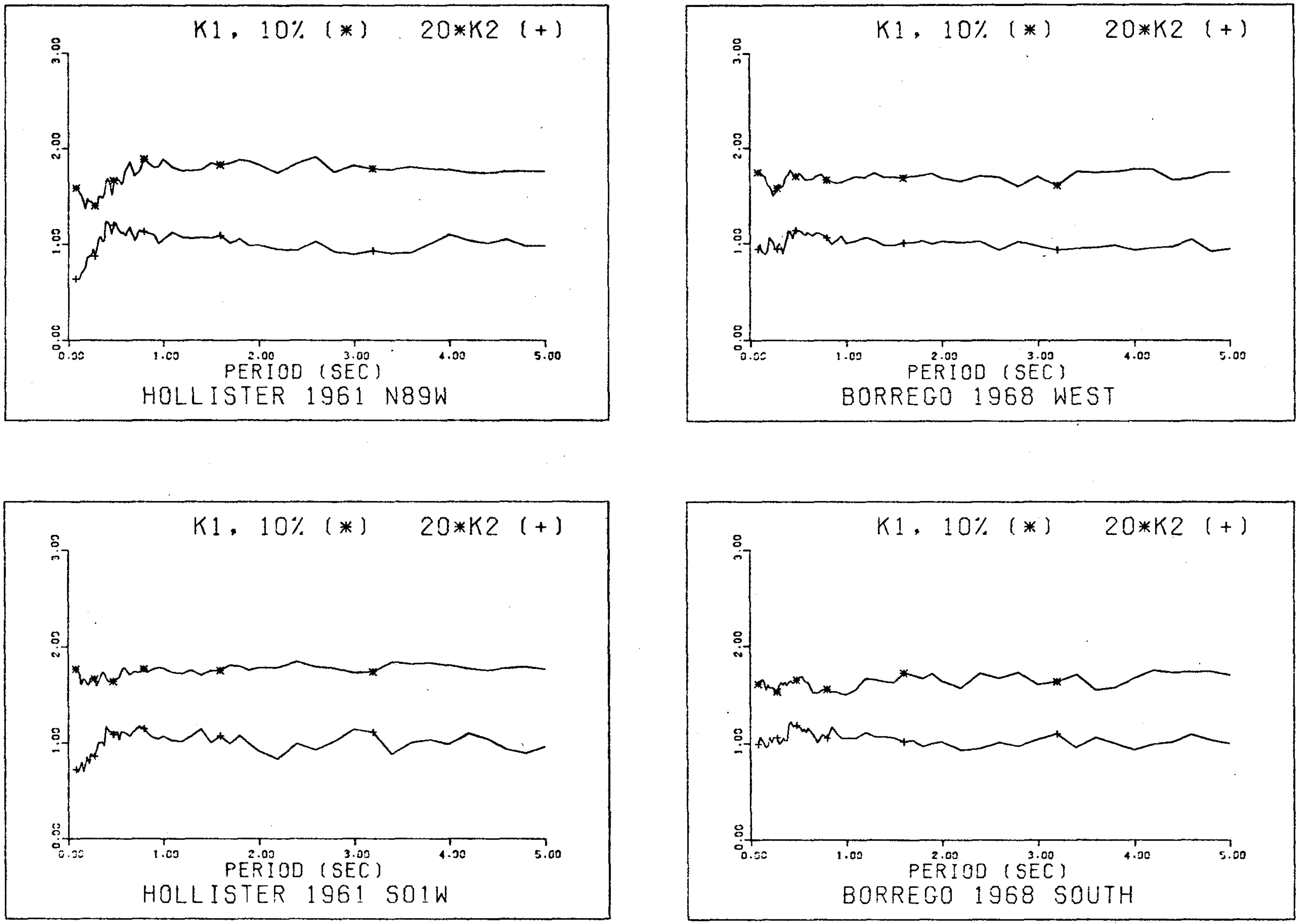
(A015)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



(A016) (A017)

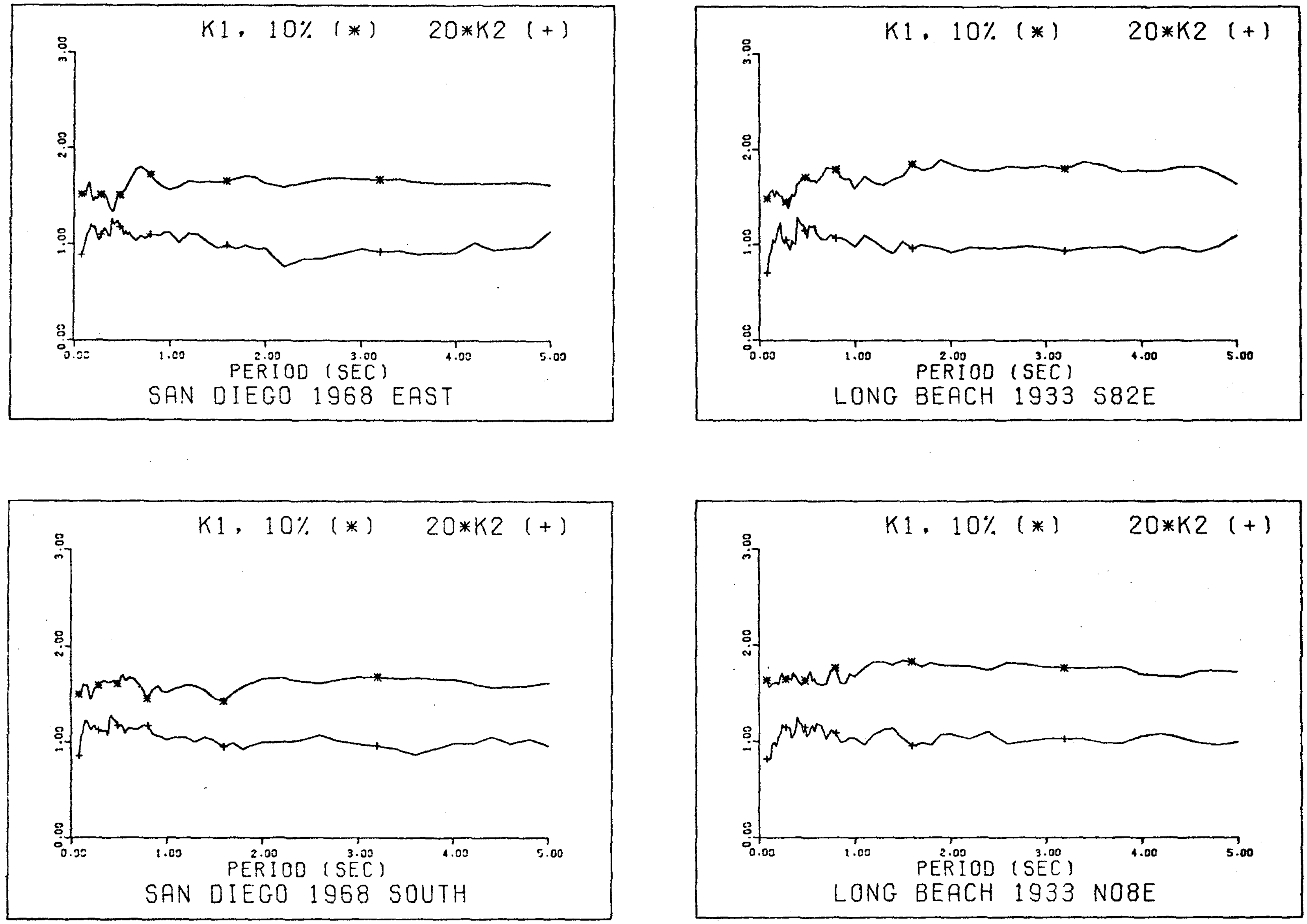
FIGURE 4.6. Factors K_1 and K_2 (Cont.)



(A018)

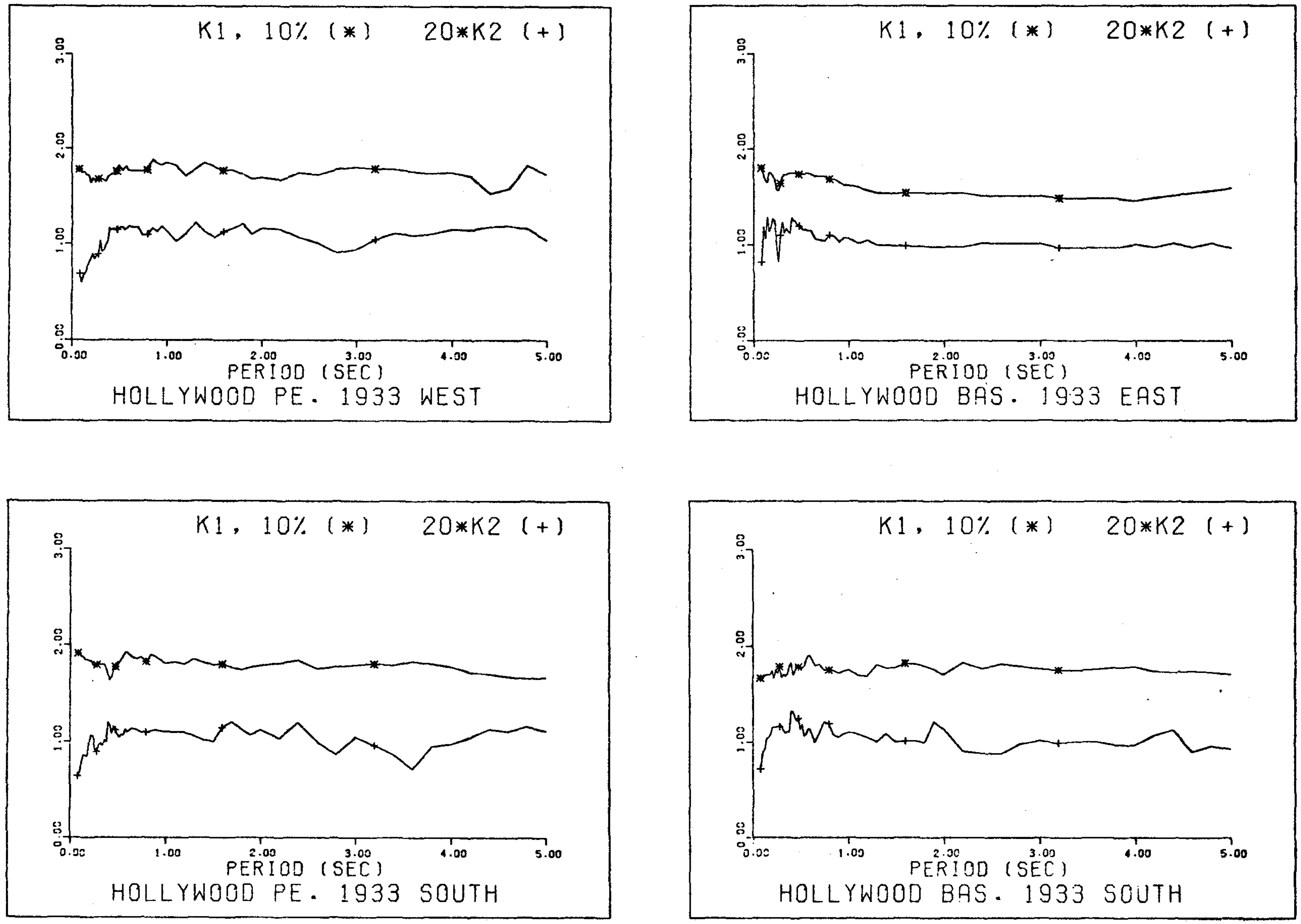
(A019)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



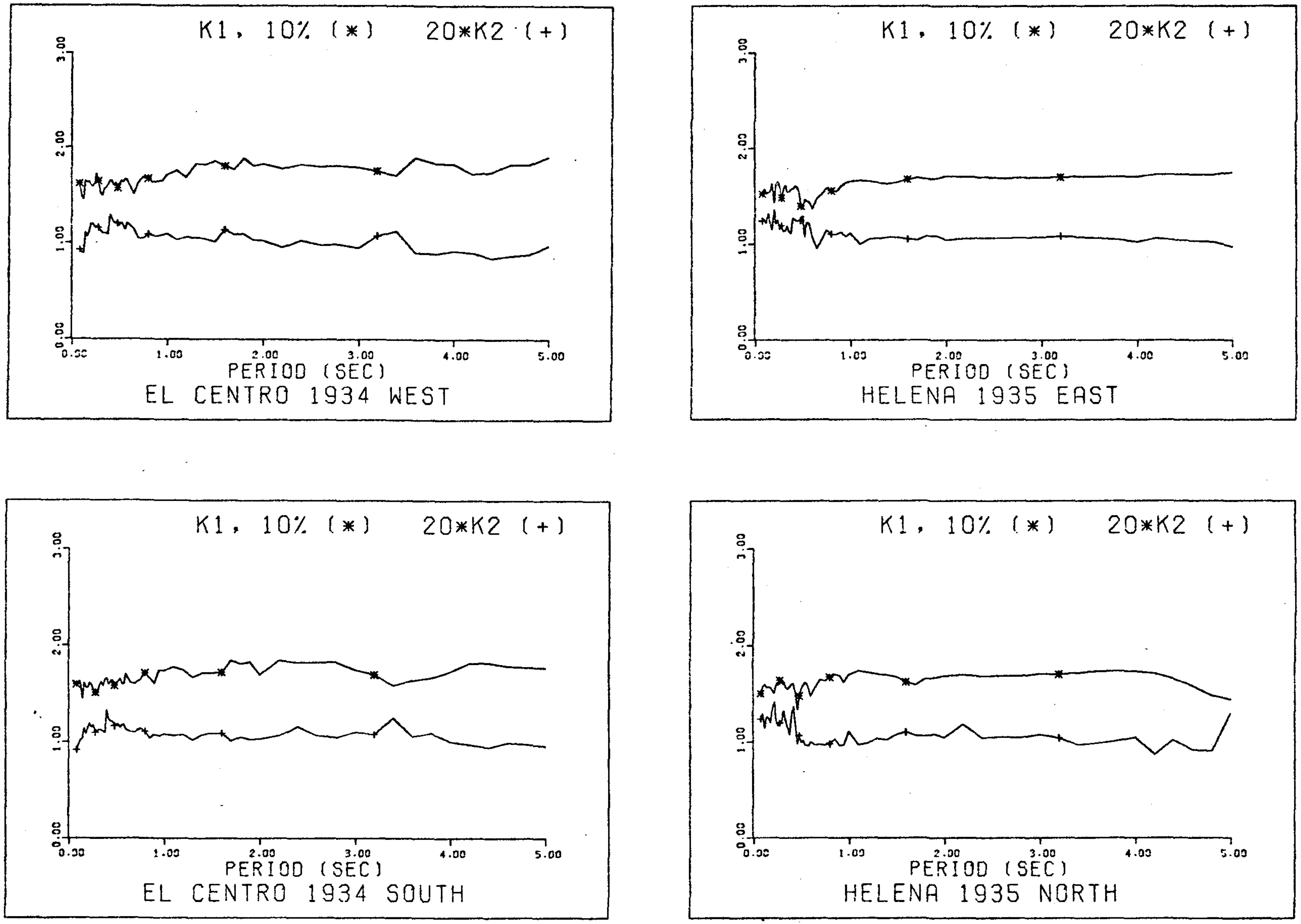
(A020) (B021)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



(B022) (B023)

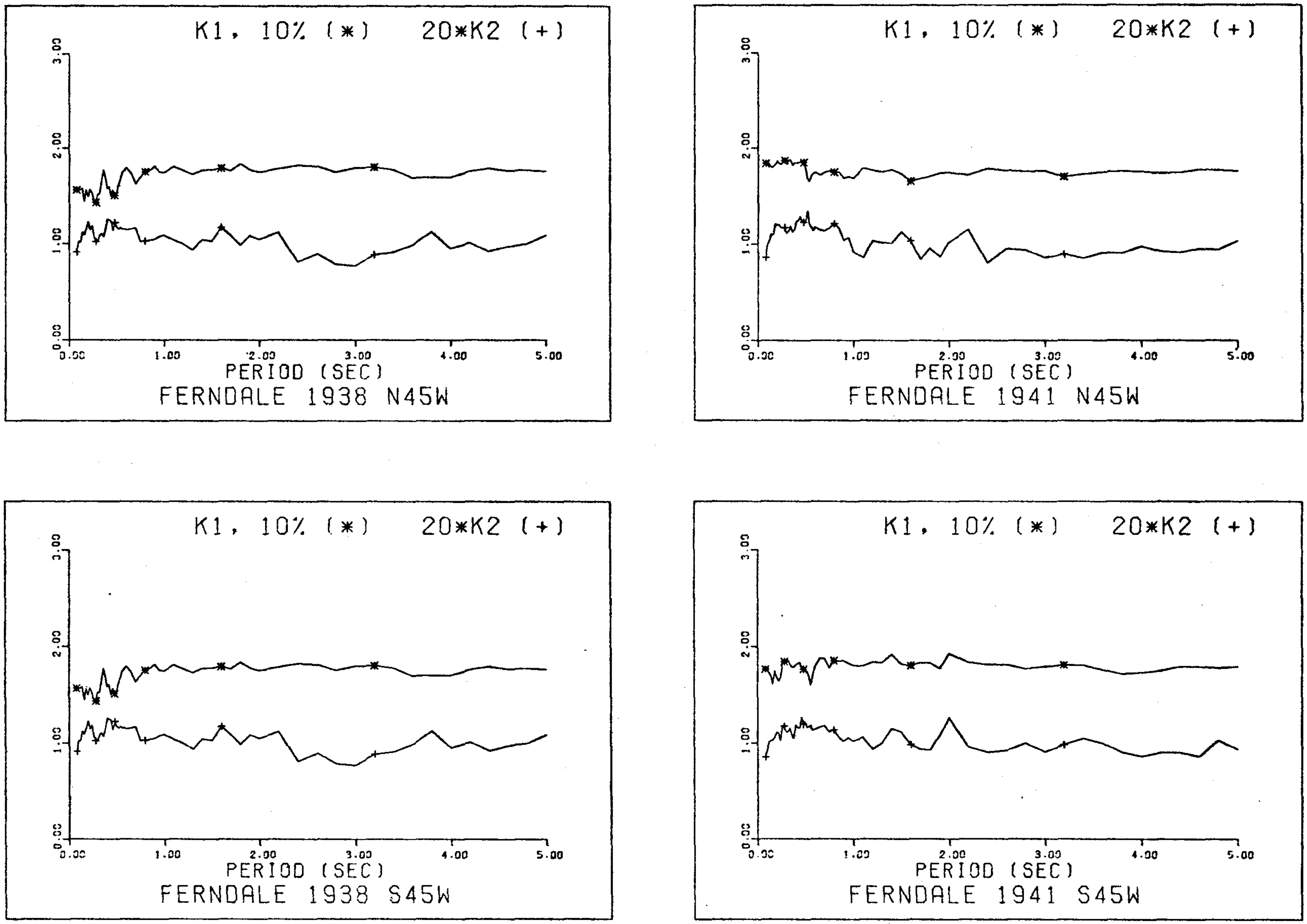
FIGURE 4.6. Factors K_1 and K_2 (Cont.)



(B024)

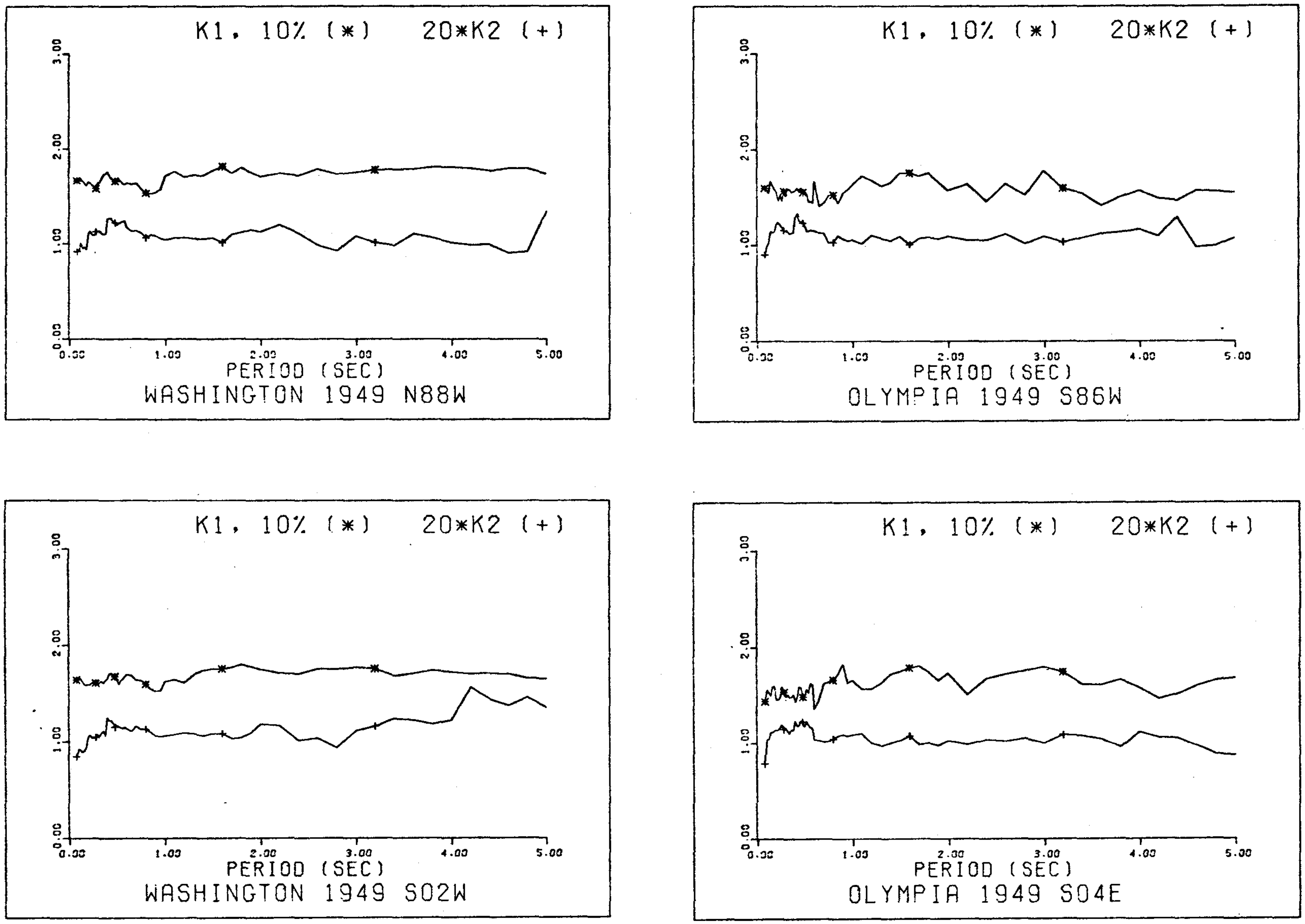
(B025)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



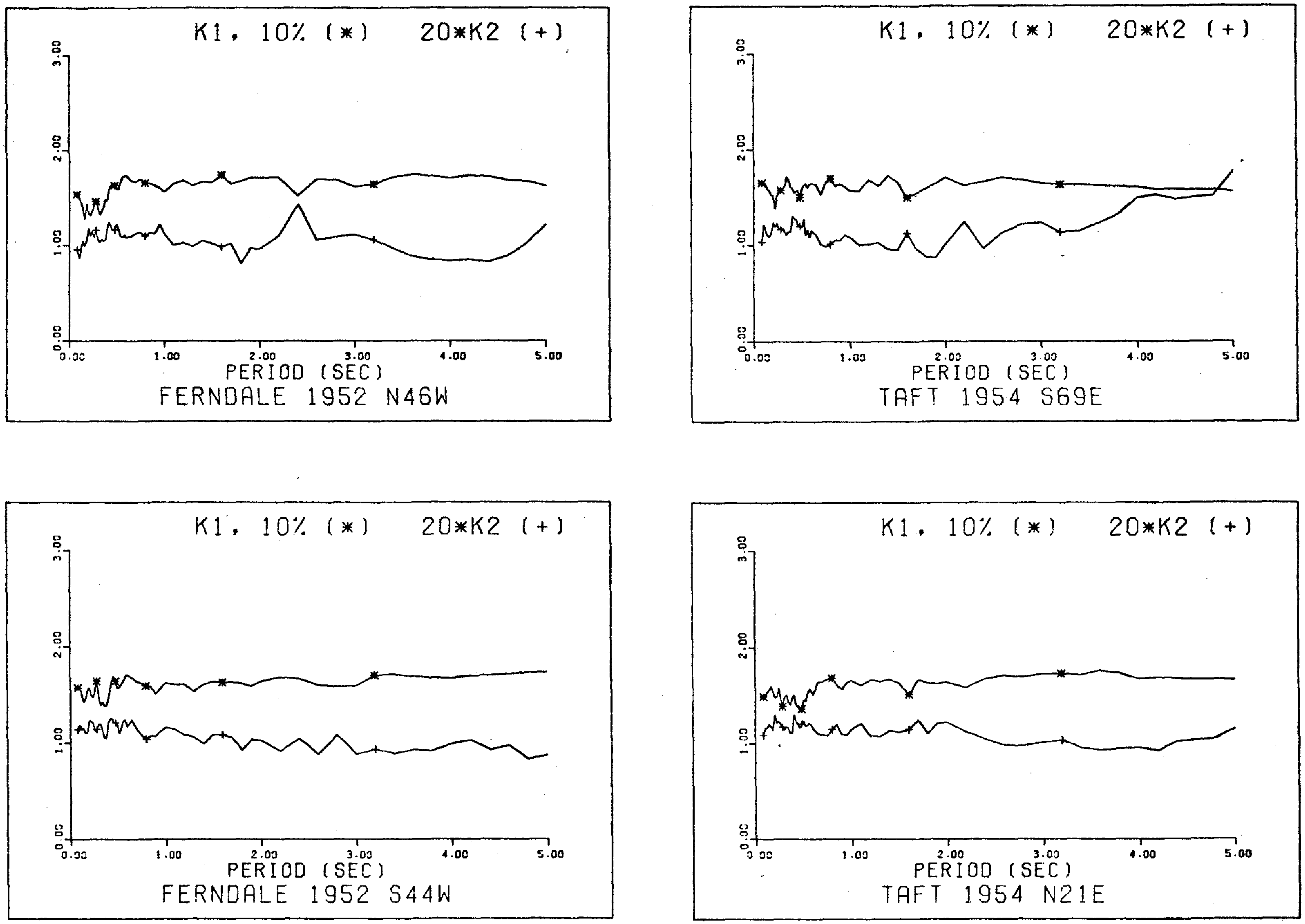
(B026) (B027)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



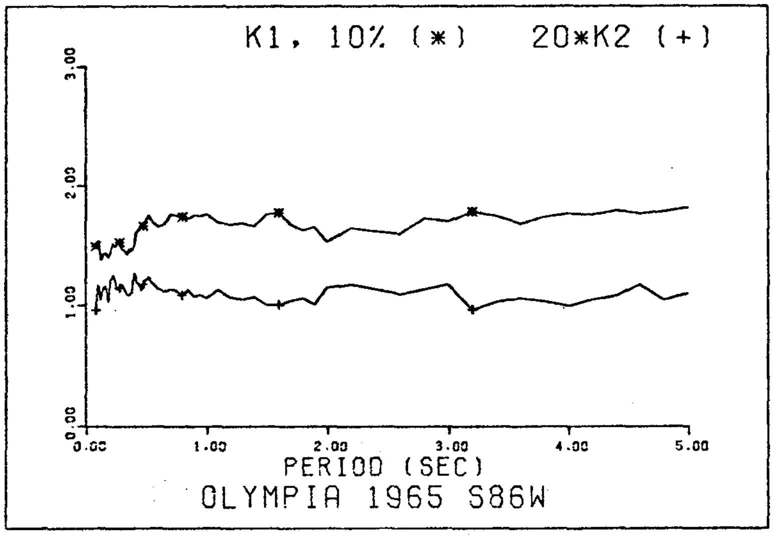
(B028) (B029)

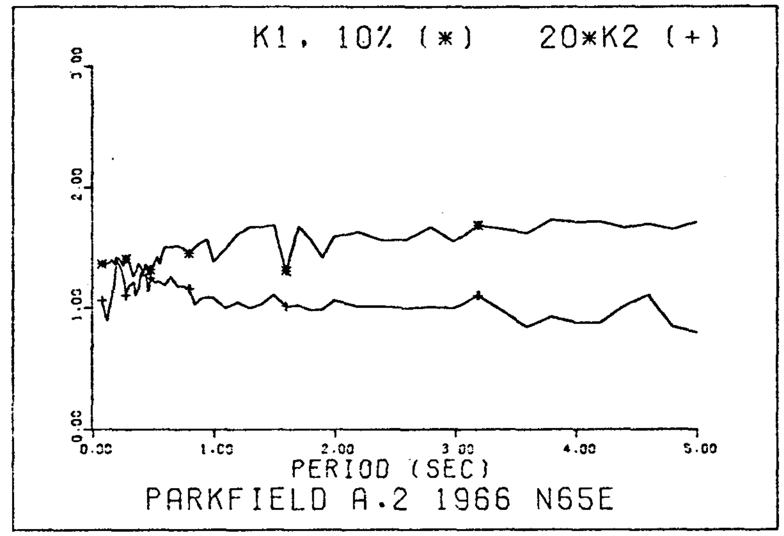
FIGURE 4.6. Factors K_1 and K_2 (Cont.)



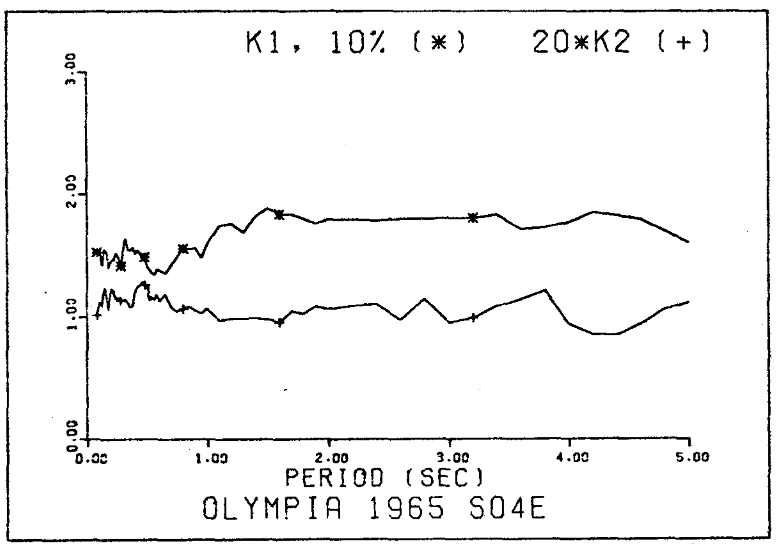
(B030) (B031)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



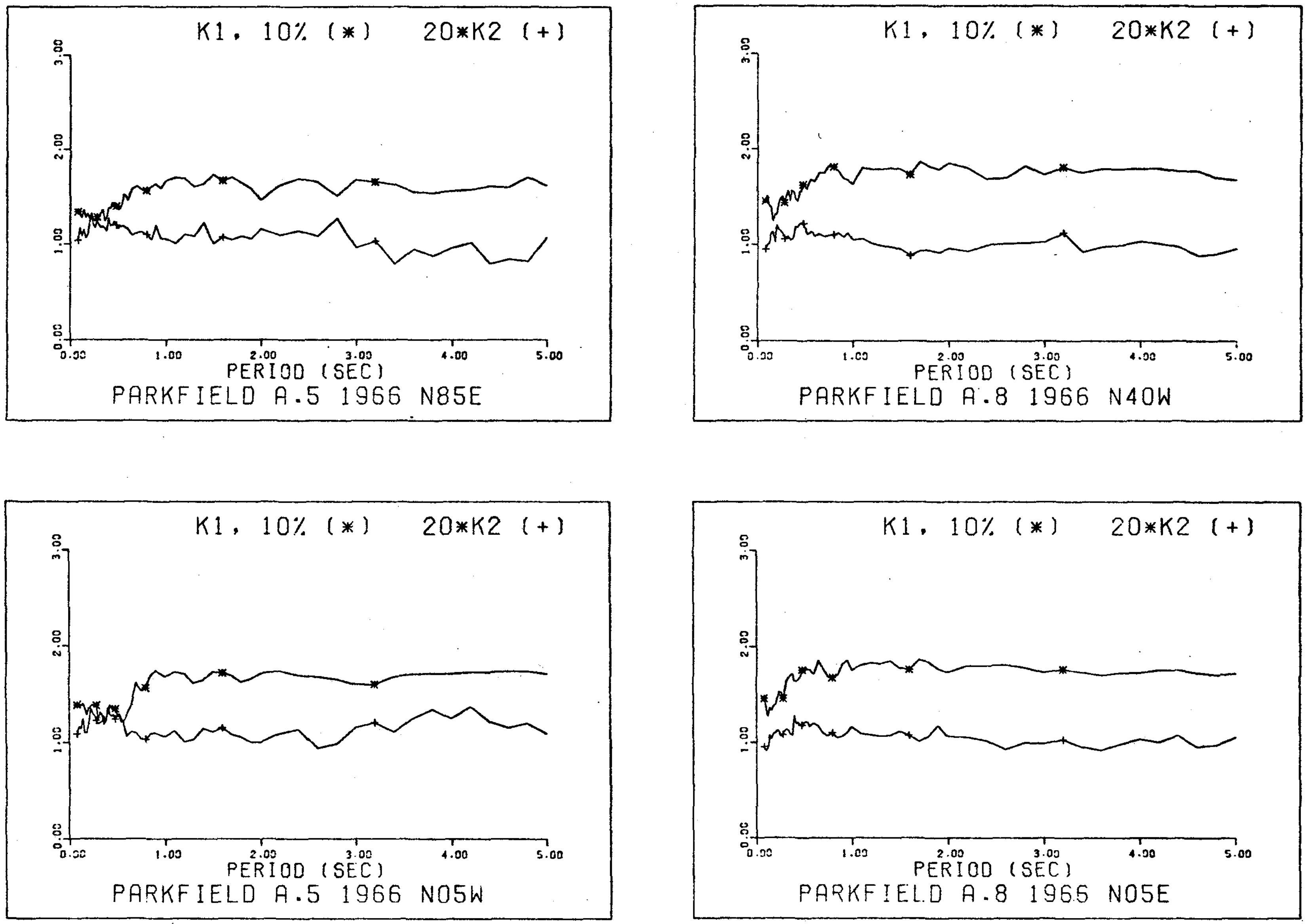


(B033)



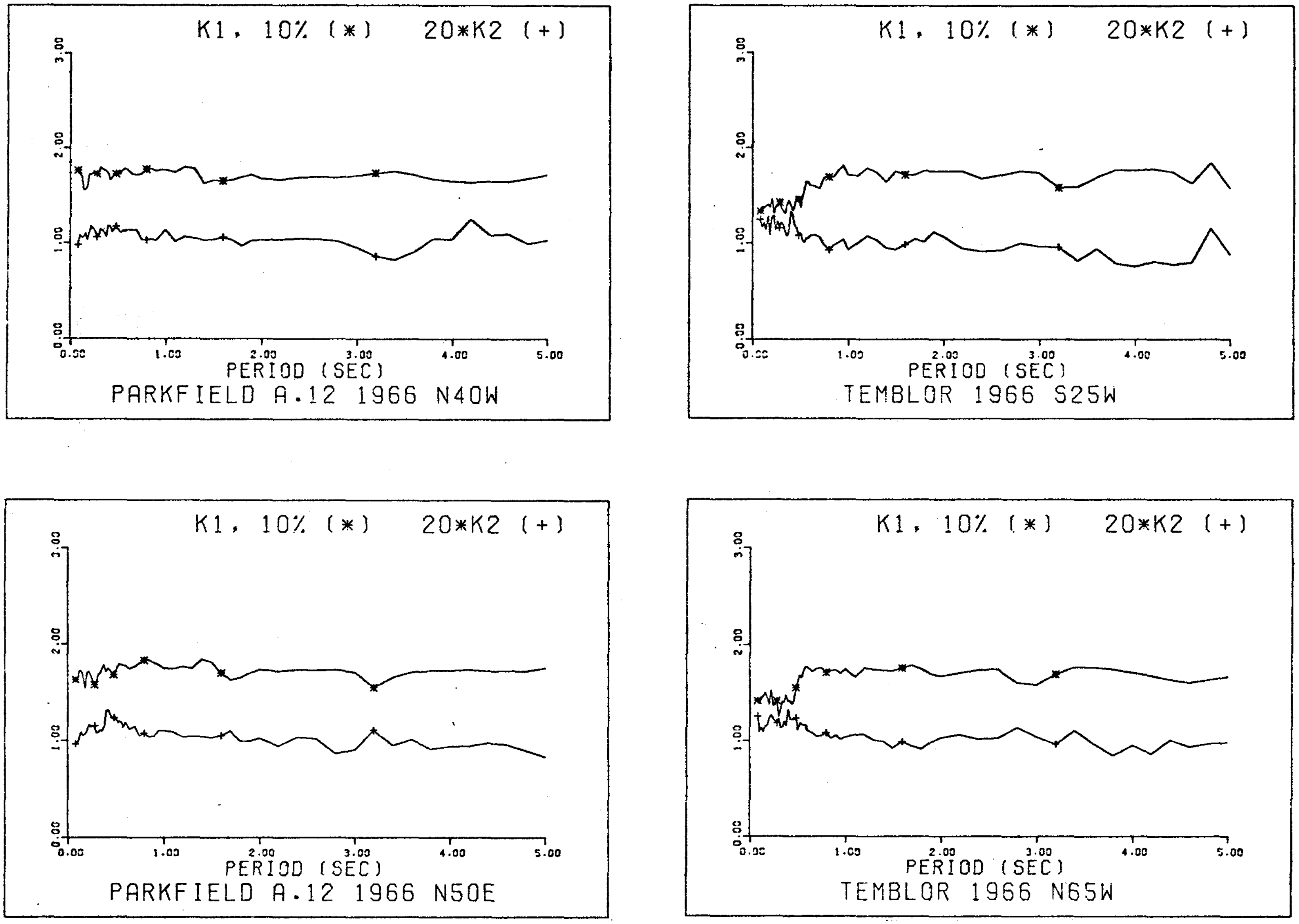
(B032)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



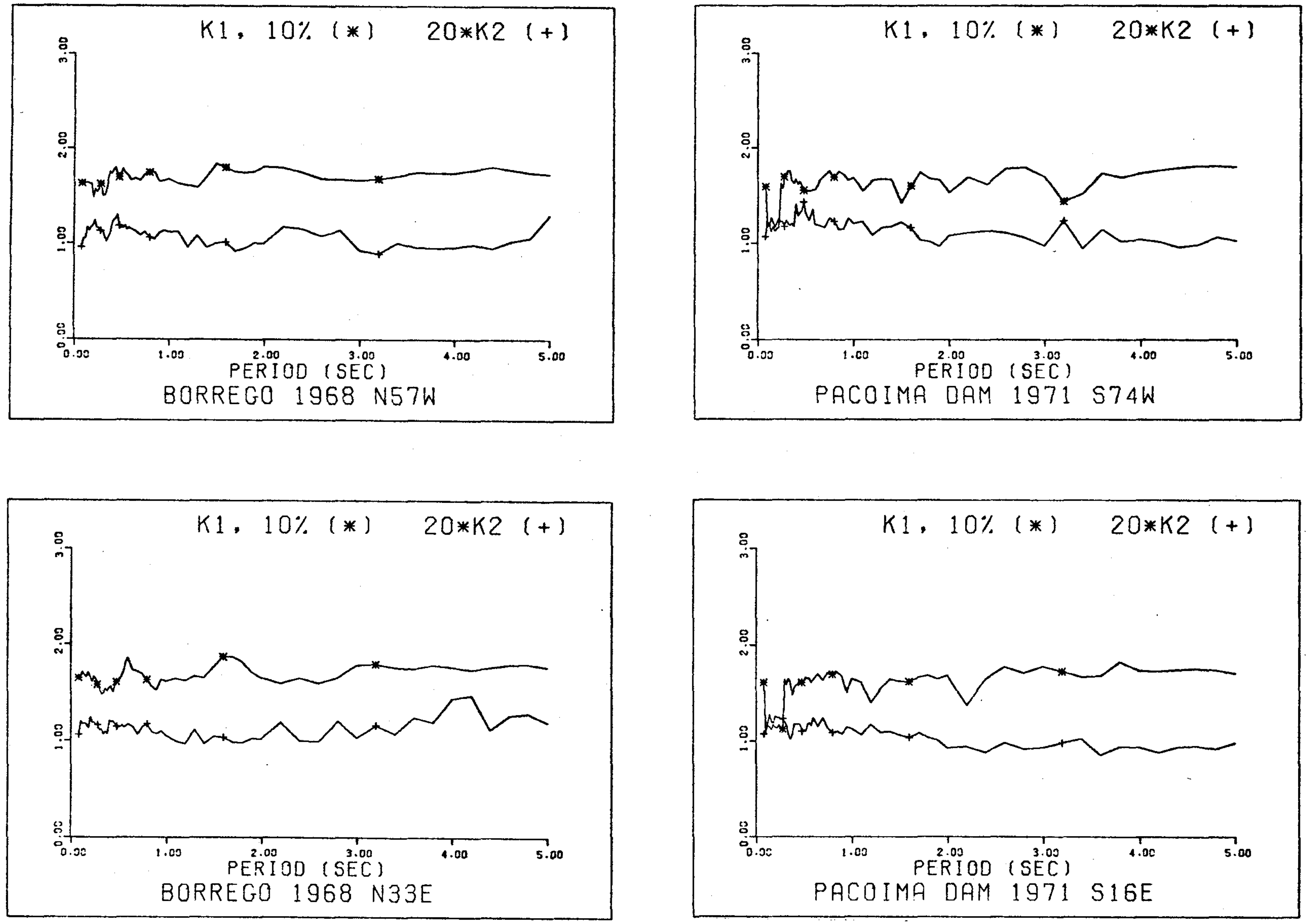
(B034) (B035)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



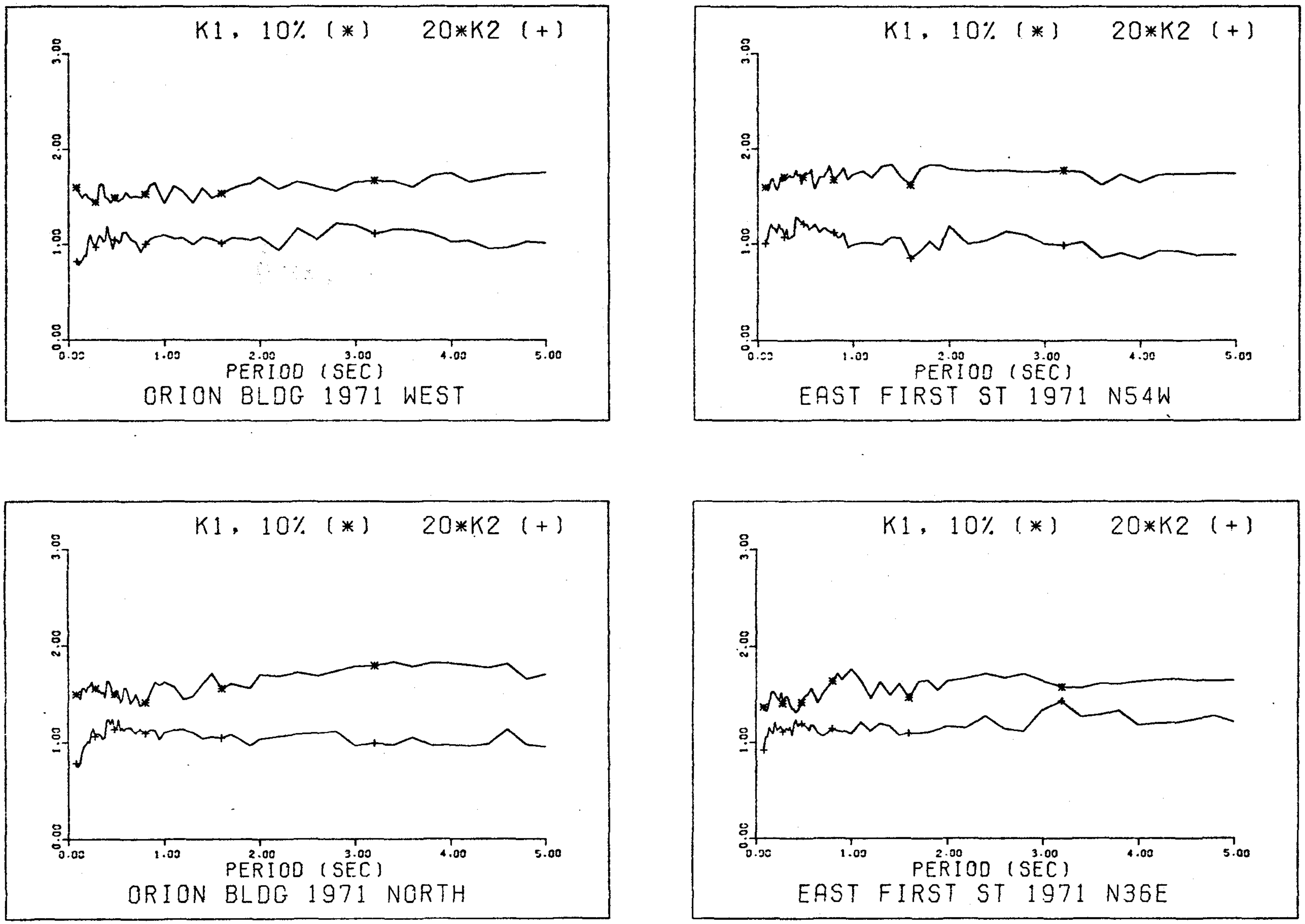
(B036) (B037)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



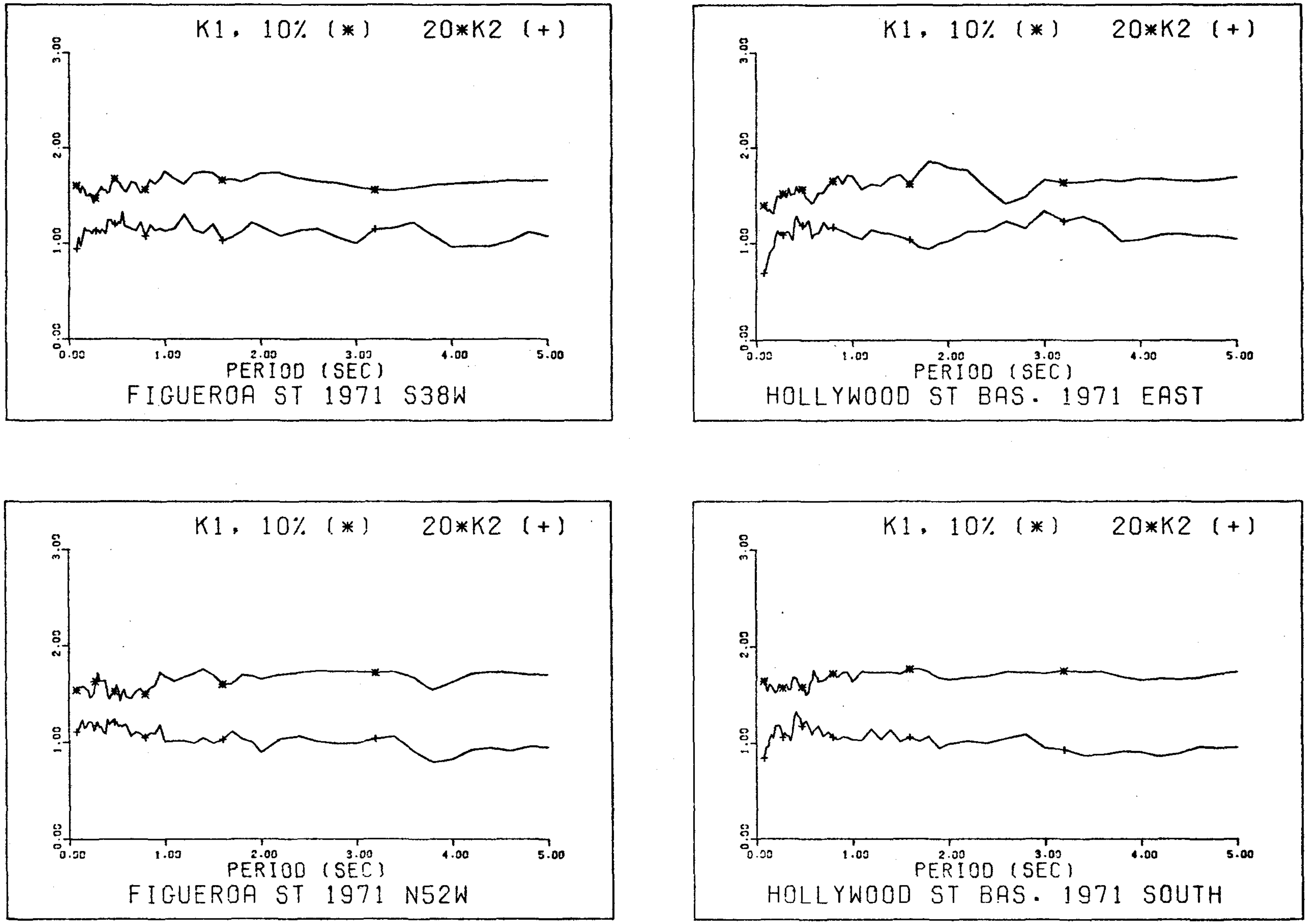
(B040) (C041)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



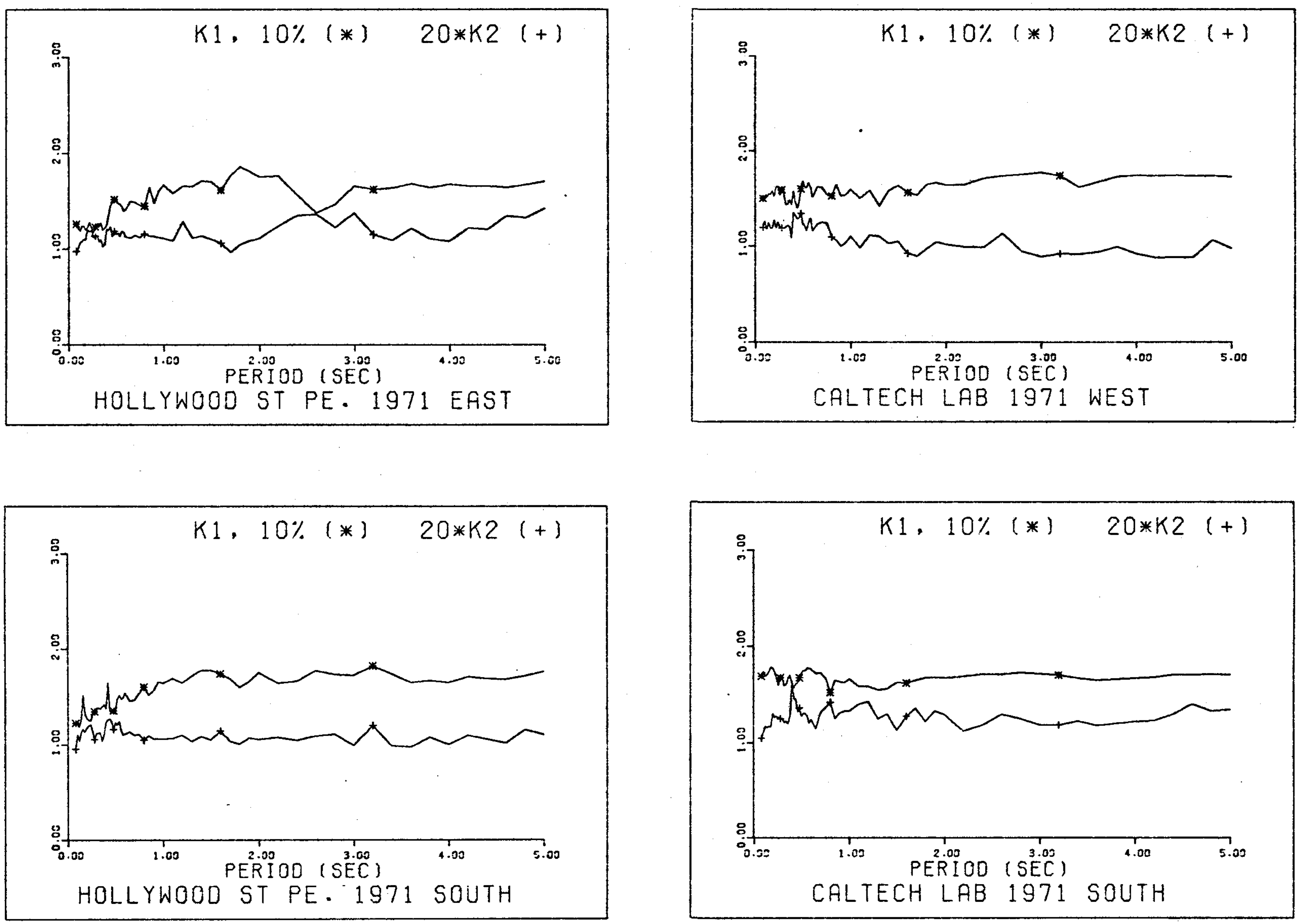
(C048) (C051)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



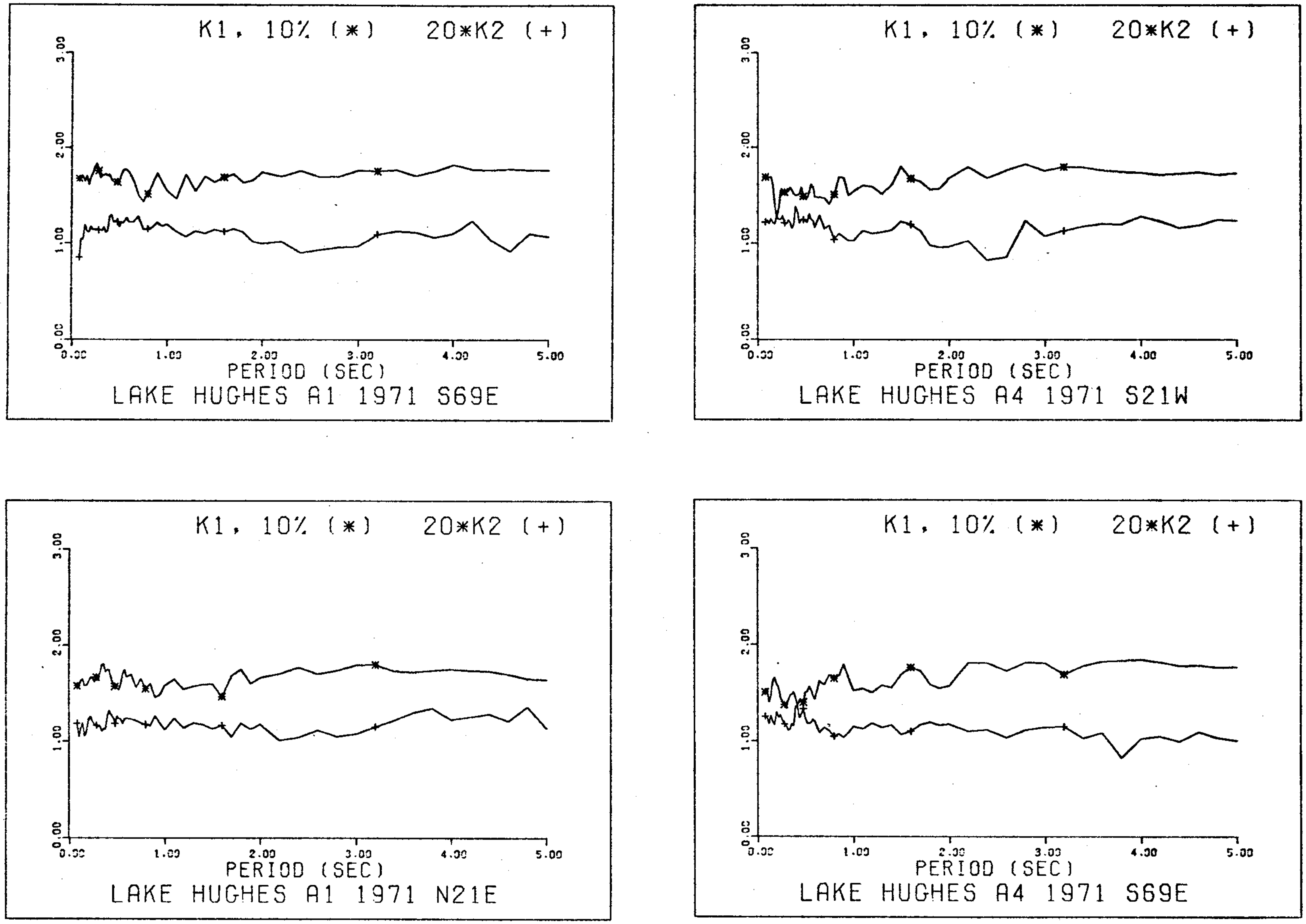
(C054) (D057)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)



(D058) (G106)

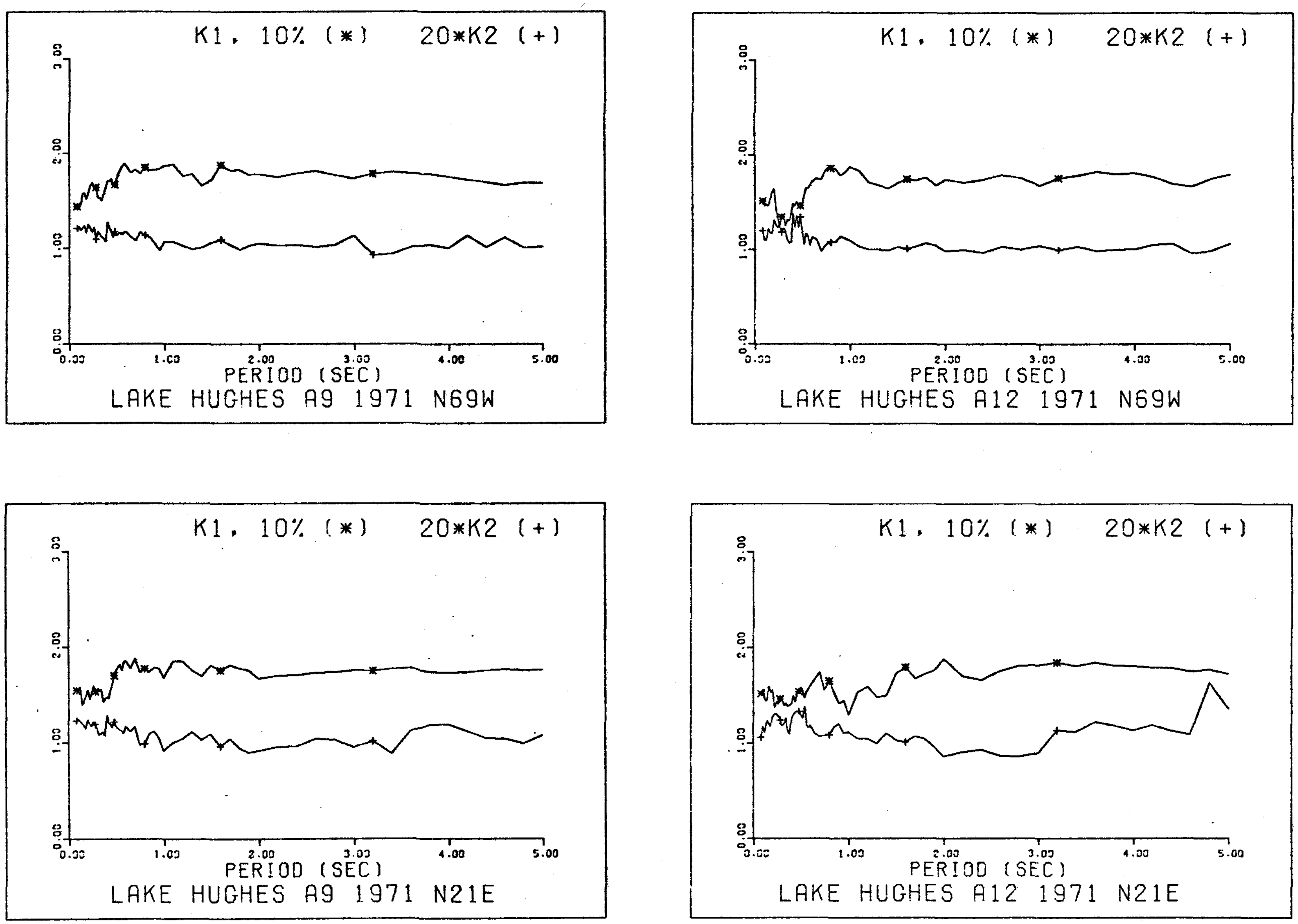
FIGURE 4.6. Factors K_1 and K_2 (Cont.)



(J141)

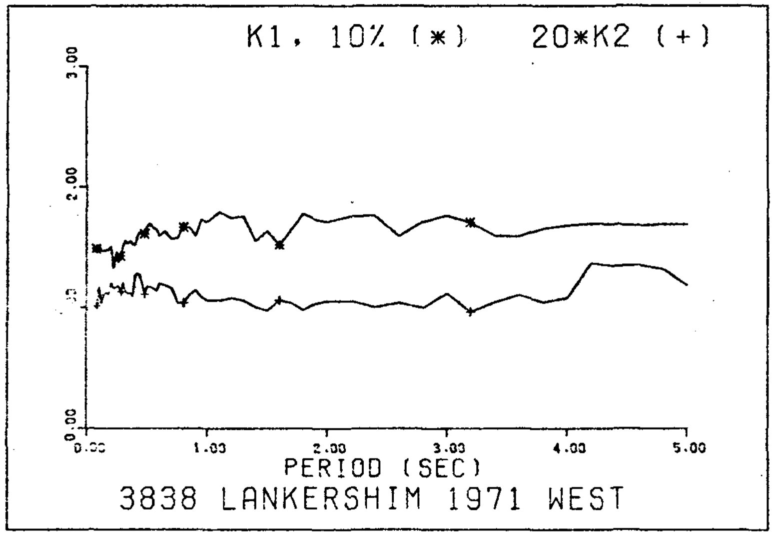
(J142)

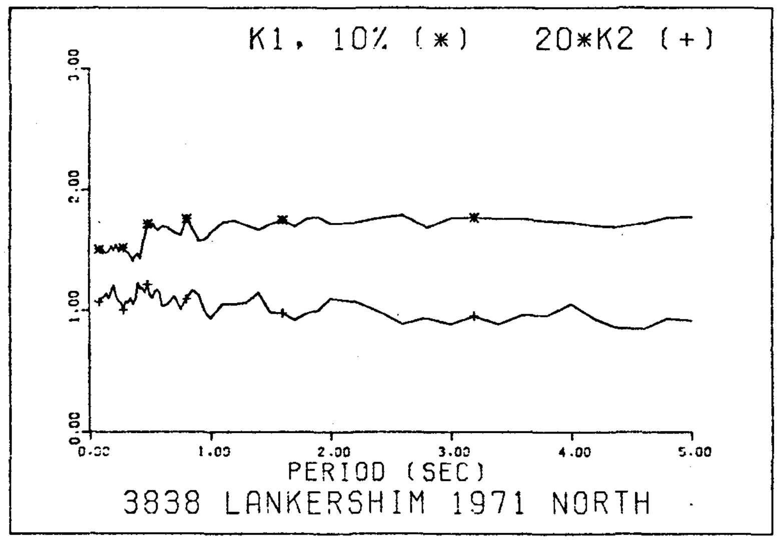
FIGURE 4.6. Factors K_1 and K_2 (Cont.)



(J143) (J144)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)





(L166)

FIGURE 4.6. Factors K_1 and K_2 (Cont.)

CHAPTER V

STABLE DESIGN PARAMETERS

5.1 Introduction

In Chapter IV, 97 earthquake accelerograms were analyzed for various parameters of possible engineering interest. The analysis of these accelerograms was conducted in two steps:

- Various parameters associated with the recorded ground motion were first analyzed. This step was necessary to understand the input characteristic of ground motion for any structural analysis. This step was also useful in determining the "zero period" frequency domain response analysis. Numerical values of the input parameters computed in this study are presented in Table 4.2.
- Parameters associated with the response of a single degree of freedom system for different periods and dampings were also obtained. This step was necessary to determine the variation in response parameters for various recorded ground motions. Appendix B gives the numerical values of all the response parameters of interest in this study.

It was mentioned in Section 1.4.2 that the above analysis was conducted with the following goals in mind:

- Develop stable parameters describing the earthquake ground motion and the response time histories. Currently used design parameters such as peak ground motion values (acceleration, velocity, displacement) or spectral response values do not seem to be good predictors of structural performance or damage potential. This is understandable because, by definition, the peak values are extremes and hence, statistically, they are not good summaries of the overall behavior.

- Relate the developed stable parameters with the currently used design parameters. This is an important and desirable goal. The current design practice is totally entrenched in the use of peak values such as PGA for recorded ground motion and response spectrum for frequency content. Unless the newly developed stable parameters can be related to these widely used quantities, their usefulness and engineering applicability will be very limited.
- Incorporate new stable parameters in the development of seismic hazard maps. If the potential seismic hazard for a region can be described in terms of parameters more stable than the peak values currently used, a better and more reliable design strategy can be developed to reduce the potential seismic risk.

In the following sections, various possible applications and justifications are given for the parameters presented in Chapter IV.

5.2 Duration of the Input Accelerogram and of the Response Time History

As mentioned previously, more research is needed to develop a standard and meaningful (in engineering terms) definition of duration both for recorded ground motion and response time histories. In this work, the record is truncated at the time when the acceleration becomes and remains smaller than 0.02 G (Table 4.1). Obviously, this is an arbitrary way of defining the earthquake duration. A better method would be to look at the rate at which, for a given record, the input energy increases with time. Duration could then be defined as the time during which 90% or 95% of the total energy is transferred. (Trifunac and Brady, 1975; Dobry, et al., 1977). This definition has the advantage of disregarding both the beginning and the end of the record. It should be noted that the value of duration selected affects the RMS and the total energy. The probabilistic duration maps developed in Chapter III can be revised and updated if a better definition of the input duration is developed. In Table 4.2 (column 4), the number of peaks (NBPK) is directly related to the input duration.

Even though most earthquake engineers are of the opinion that the damage potential of a given structure increases with an increase in response duration (for a given response amplitude), no design parameter explicitly dependent on duration is currently used. In this work, the response is arbitrarily terminated when the response acceleration peak reaches 10% of the highest response peak and does not exceed that value thereafter. The numerical values are listed in seconds in Appendix B (column 3). They are used to calculate the RMS and the cumulative potential energy of each response. No detailed analysis of the definition of duration is conducted in this study. However, it can be seen that the duration of the response is a function of the input duration, input frequency content, the oscillator natural frequency and the damping (Fig. 4.3). It is interesting to note that a small spectral acceleration value could be associated with a long duration and hence large potential energy. Figure 5.1 shows two response parameters, S_a and ENGY, on a normalized scale such that their shapes can be compared. Contrarily to S_a, the value of ENGY is a function of duration. It can

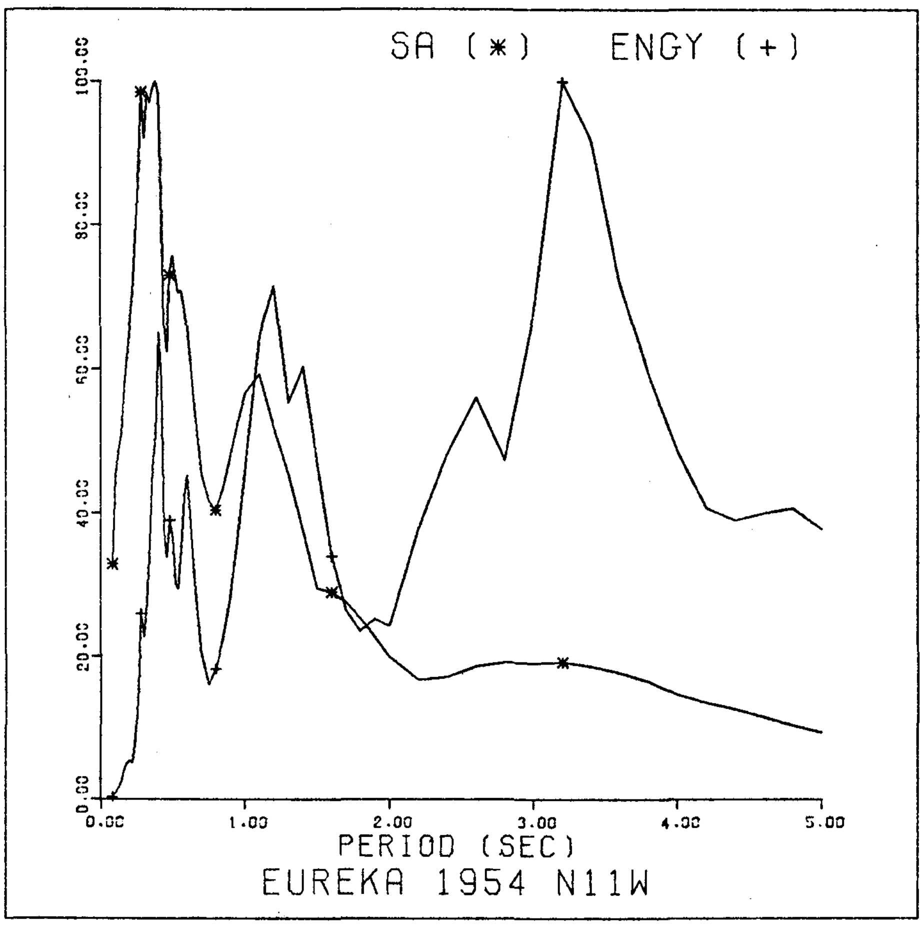


FIGURE 5.1. S_a and ENGY Plotted on Normalized Scale

be seen that in this case for longer period oscillators, the relative value of ENGY is much larger than the corresponding S_a. It is hoped that in the future the damage potential could be better correlated with the duration dependent parameter ENGY than it is today with S_a. More will be said about this parameter in a later section.

5.3 RMS of the Input Accelerogram and of the Response Time History

As mentioned previously in Chapter IV, peak amplitudes by themselves are poor indicators of seismic loading. Probabilistically, they show great scatter. A better parameter defining the amplitude of the input ground motion and of the response spectral value is the root mean square (RMS). Since the RMS is a statistical summary of many peaks, the scatter of this parameter between two similar events (same magnitude, same distance) is small compared to the scatter of peak values. Also, the attenuation relationship for the RMS amplitude with distance should be more stable (with less scatter) than the attenuation relationship for peak values. The values given in Table 4.2 (column 5) are the RMS for the various input accelerograms. They are also the zero period value of the "RMS response spectrum". Values of the "RMS response spectrum" for the other periods are given in Appendix B (column 5). Figure 4.4 shows the RMS response spectrum for all the 97 accelerograms considered. On the same plot, the conventional acceleration spectrum (S_a) is also shown. From these plots, the following observations can be made.

- The general shape of the RMS acceleration spectrum is similar to the general shape of the acceleration response spectrum.
- The RMS acceleration spectrum is always smaller than the acceleration response spectrum
- The shape of the RMS acceleration spectrum is "smoother" than the shape of the acceleration response spectrum. The RMS response spectrum represents a statistical summary of all the response peaks and hence has a lower probabilistic scatter.

From the above observations, it can be said that a design spectrum obtained by scaling upward the RMS spectrum (depending on the level of the acceptable probability of exceedence) will be smoother and will contain more probabilistic information than the acceleration spectrum used currently.

It is also worthwhile to note that a total design methodology based on RMS input and response may not be too far-fetched. Thus, hazard maps could be developed where probabilistic information on various RMS amplitude levels could be presented. This could be achieved by developing RMS amplitude attenuation curves and using them in estimating ground motion information at the site. Instead of using acceleration, velocity or displacement response spectra for design, probabilistic response spectra developed by using RMS response spectra (Fig. 4.4) and a multiplying factor could be developed. This aspect of developing probabilistic spectra will be described in the next section.

5.4 Study of the Stable Parameter K_1

In Chapter IV, it was shown that for all the input accelerograms and the response time histories, the shape of the acceleration amplitude distribution was gamma or exponential. Assuming, for simplicity, that the exponential distribution is acceptable, the parameter λ of the distribution is given for all cases considered in Appendix II (column 6). If the assumption of the exponential distribution for the input or response peaks is valid, the following derivation can be made.

Figure 5.2 represents schematically the shape of the peak distribution whether they belong to the input accelerogram or to the response of an oscillator of period T and damping β.

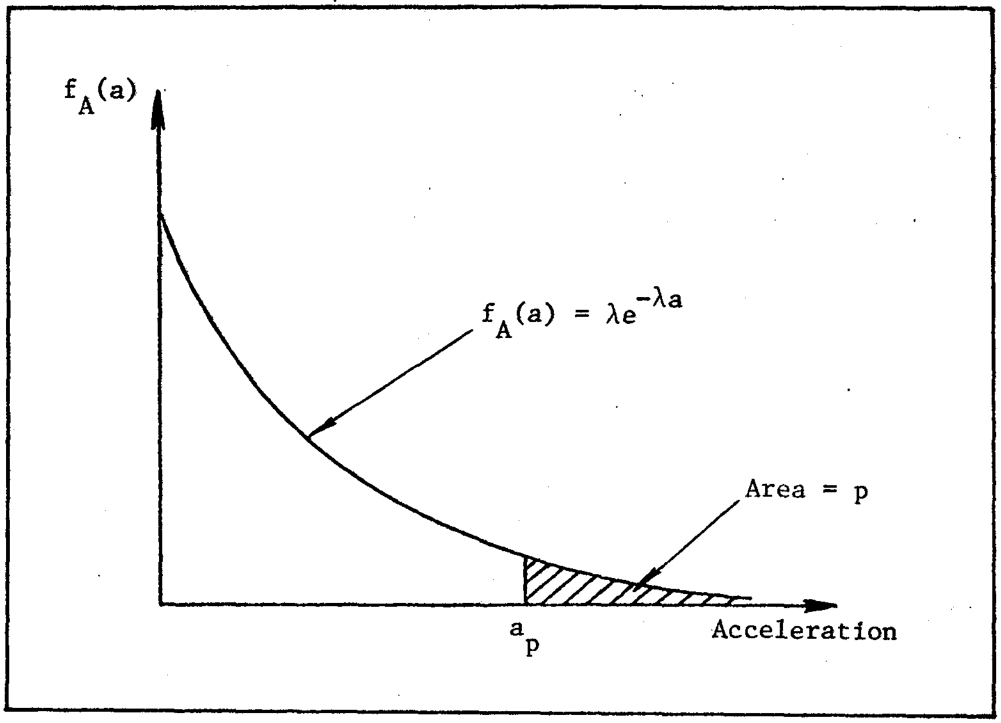


FIGURE 5.2. Exponential Distribution

The RMS value for this distribution is given by

$$RMS = \frac{\sqrt{2}}{\lambda} \tag{5.1}$$

Considering the acceleration a_p which has p% chance of being exceeded

$$e^{-\lambda a_p} = p$$

or

$$\lambda a_p = \ell n(\frac{1}{p})$$

Hence

$$a_p = \frac{1}{\lambda} \ell n(\frac{1}{p}) \tag{5.2}$$

and the ratio

$$K_1 = \frac{a_p}{RMS}$$

$$= \frac{\ell n(\frac{1}{p})}{\sqrt{2}} \tag{5.3}$$

From equation 5.3 it can be seen that the ratio K_1 depends only on p and is independent of λ or the individual peaks. Thus, for $p = .05$, K_1 should be 2.12 and for $p = 0.10$, K_1 should be 1.63.

The values of K_1 ($p = 0.05$ and 0.10) for the input accelerograms are given in Table 4.2 (columns 9 and 10). It is worth noting that the values of K_1 for $p = 0.05$ range between 1.33 and 2.51 with a mean of 2.00 and a standard deviation of 0.24. For $p = 0.10$, the values of K_1 range between 1.02 and 1.93 with a mean of 1.54 and a standard deviation of 0.19. A detailed study of the ratio K_1 as a function of the input accelerogram, soil condition, distance, magnitude, etc., is needed. The values of K_1 ($p = 0.05$ and 0.10) for the response time histories, are given in Appendix B (columns 10 and 11). It is remarkable to note that for all earthquakes, all periods and all dampings, this ratio is a constant and very close to the theoretical value obtained using the exponential distribution (eq. 5.3). Figure 5.3 shows the mean and the standard deviation of K_1 versus period for all the accelerogram responses considered.

If the value of the damping varies from 5% to any other value such as 10% or 20%, the value of K_1 does not change appreciably. Figure 5.4 shows a typical behavior of K_1 ($p = 0.10$) as a function of damping. This type of behavior is typical for all the accelerograms and response time histories. From the numerical results presented in Chapter IV, in Appendix B and from the above discussions, the following statements can be made about the ratio K_1:

- For a given probability of exceedence, the value of K_1 is very stable.

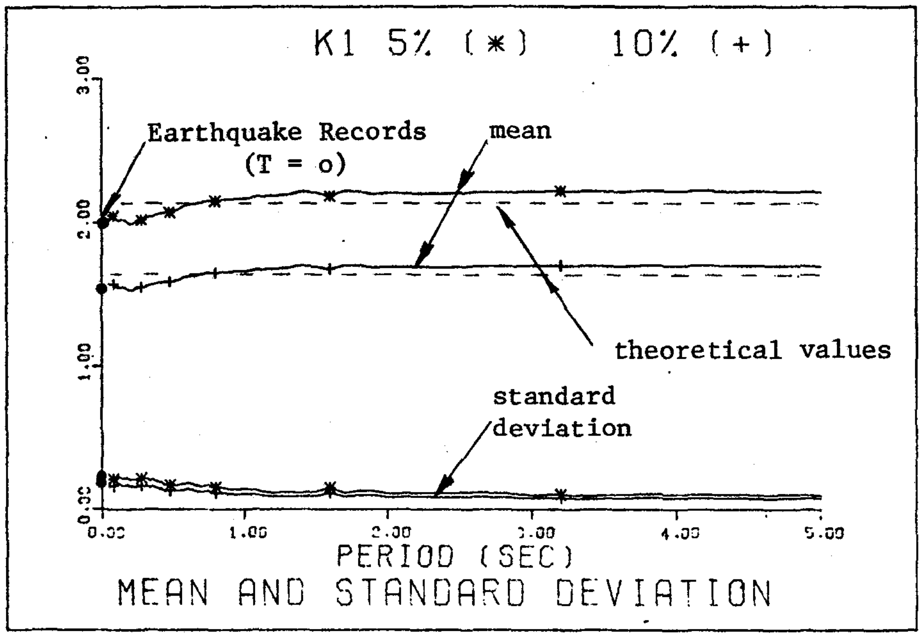


FIGURE 5.3. Factor K_1 (Statistics for 97 Responses)

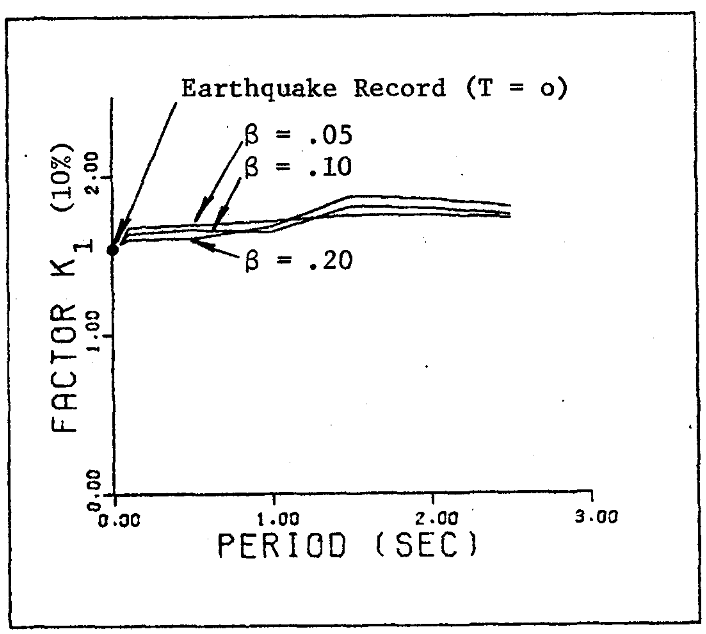


FIGURE 5.4. Typical Behavior of Factor K_1 for Different Dampings β.

- The numerical value of this constant varies with the parameter p but is independent of

  A) the period of the oscillator

  B) the damping

  C) the input accelerogram

- Using the exponential assumption, the theoretical value of K_1 for $p = 0.05$ and 0.10 should be 2.12 and 1.63 respectively. Theoretical and actual values are plotted for comparison in Figure 5.3.

- The remarkable stability of K_1 and the relative stability of RMS can be utilized for deriving response spectra that can be considered as an "equal probability spectra". The values of the equal probability spectra have the same probability of being exceeded for all period bands. In Figures 4.4, the response spectra for all the accelerograms considered in this study were presented. These spectra do not have any probability statement associated with them. Thus development of response spectra which are associated with a predetermined level of non-exceedence essentially constitutes a refinement and an improvement in the current procedure. If for a given region and for a given damping, the shape of RMS versus period can be estimated, then using the stable parameter K_1 any probabilistic spectrum can be generated.

Using

$$a_{p_T} = K_1 \cdot RMS_T$$

where K_1 depends on p and is constant for all periods and dampings

RMS_T is the RMS corresponding to period T

a_{p_T} is the acceleration corresponding to period T and having a probability p of being exceeded.

A response acceleration spectrum can be developed for a given probability of exceedence p . Figure 5.5 shows the probabilistic spectra developed from the RMS spectra. The multiplication factor K_1 for two values of p is given in Figure 5.3. Thus, the use of K_1 can help in elegantly developing a probabilistic response spectra if the RMS spectrum is given. It is generally felt by seismologists and engineering geologists that a "design RMS spectrum" would be easier to obtain for a given region than the response spectrum. It should be emphasized that much more work is needed on this particular aspect before the stable parameter K_1 can be used for practical development of probabilistic spectrum.

5.5 Study of the Stable Parameter K_2

In Chapter IV, the cumulative potential energy per unit mass was defined and numerically calculated for all the response time histories. Appendix B (column 9)gives the numerical values of this parameter.

In the engineering profession, it is often mentioned that the damage potential of a structure increases with an increase in seismic

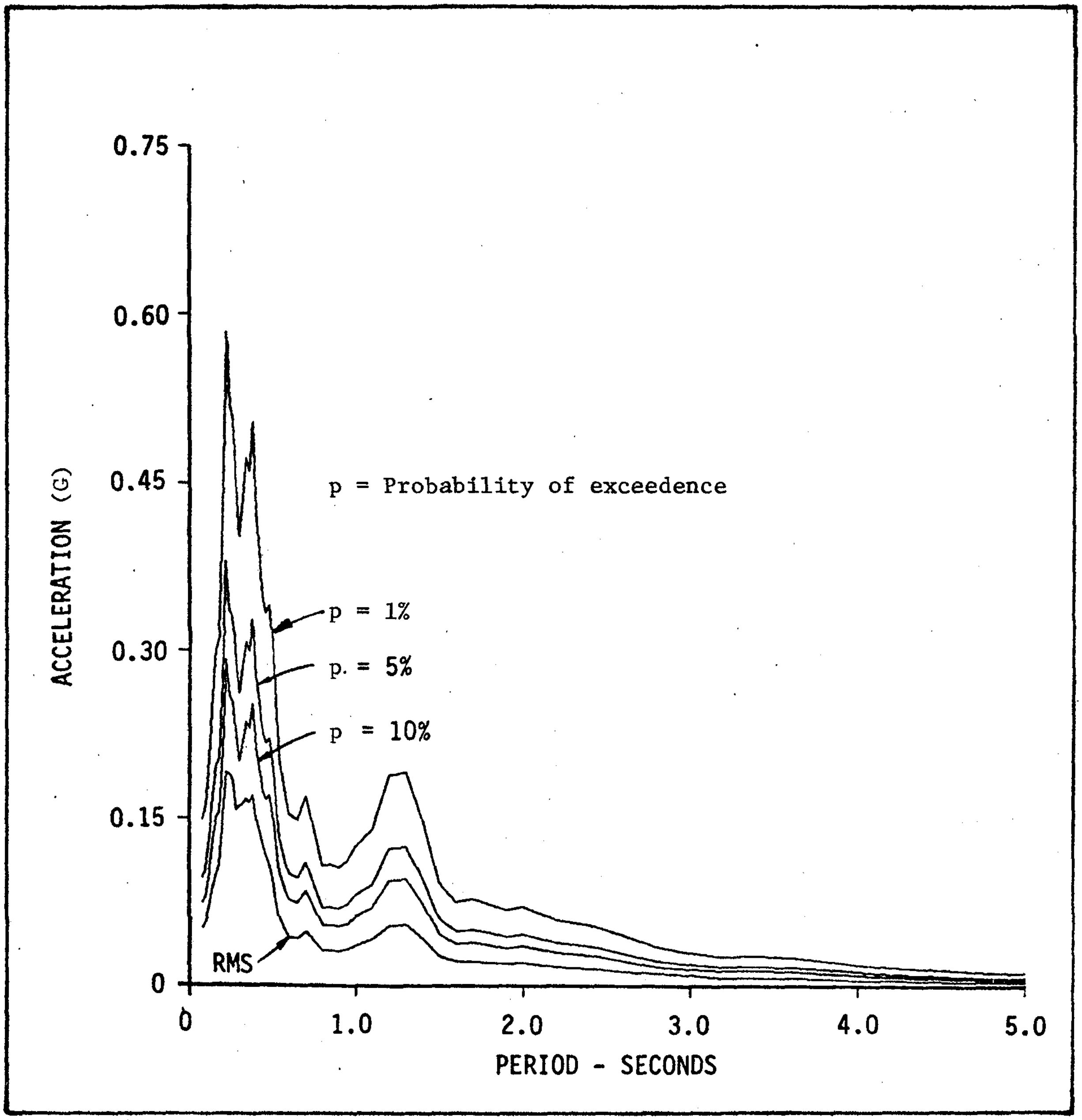


FIGURE 5.5. RMS and Equal Probability Spectra

energy input. Thus, it is quite conceivable that in the future, an energy based method of design could be developed. At the time of this writing, no such comprehensive method is available. Also, if one can develop "energy spectra", it would be desirable to relate the "energy spectra" to the conventional response spectra. For this purpose, another stable parameter (K_2) is evaluated for all the response time histories.

$$K_2 = \frac{RMS^2 \cdot T^2}{(ENGY/NBPK)}$$

where T is the period of the oscillator

RMS is the RMS of the response

ENGY is the potential energy of the response

NBPK is the number of peak in the response

It is found that the ratio K_2 is also almost constant for all the periods of the oscillator, Figures 4.6 show the behavior of this ratio for all the records considered. Figure 5.6 shows the mean and the standard deviation of K_2 versus period for all the accelerogram responses considered. It can be seen that this parameter is quite stable. An in-depth study of this ratio and its practical application is beyond the scope of this study. However, one possible use of this parameter could be as follows:

For a given "energy spectrum" and the ratio K_2, the RMS spectrum could be obtained. Then using the ratio K_1 and the RMS spectrum, a probabilistic response spectrum can be derived. Thus, with the use of K_1 and K_2, a "mapping" procedure between the currently used parameter (response spectrum) and a future design parameter (RMS or ENGY) can be developed.

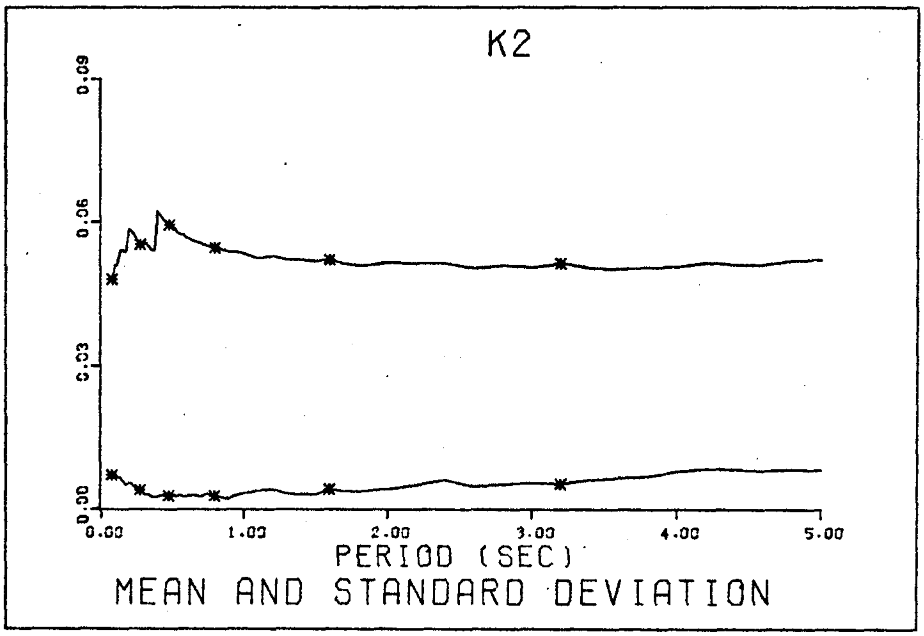


FIGURE 5.6. Factor K_2 (Statistics for 97 Responses)

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of Present Work

In this report, a Bayesian procedure for seismic hazard mapping is developed. As a case study, it is applied to Nicaragua. The method developed has the advantage of combining, in a rational and consistent way, all the available historical, seismological and geological information. This increases the versatility and reliability of the proposed method especially in cases where the historical data is scarce or the time period for which historical data is available is short.

The mapping parameters considered for this study are the peak ground acceleration (PGA) and the duration of the strong ground motion. In order to be consistent with the probabilistic approach of the model and to take into consideration the large scatter for attenuation data (for the peak ground acceleration and the duration), probabilistic treatment of the attenuation relationships in the form of coefficient of variation is presented. A uniform probability distribution function is assumed for the PGA and the duration at a given distance and for a given magnitude.

Comparison between the iso-acceleration maps developed in this study with previous results (Shah, et al., 1975) is made. It is shown that for the same data base, the shape of the iso-acceleration lines is very similar. However, for this study the numerical values of the expected peak ground accelerations change with the degree of uncertainty in attenuation equations. No comparative results are available in the literature. The iso-duration maps are also unique and again no comparable results are available in the literature.

developed in this work may help in dissipating some of those doubts. There are various major faults around the world where not a single major seismic event has occurred in historical time. However, these faults are considered potentially very active. With the previous methods of developing probabilistic hazard maps, the fault would be considered inactive leading to incorrect estimate of the potential hazard. With the Bayesian method presented in this work, the seismicity of the fault could be realistically evaluated.

There may be cases where there is no subjective geological information. In that case, using a diffuse prior and the historical data, the seismicity of the region can be estimated.

- The explicit use of the probability attenuation relationship is another new development in the hazard mapping methodology. Past data on peak ground acceleration or duration,when plotted against distance, have shown great scatter. Using a single curve through these scattered points is not realistic. In the method developed here, the scatter in the data is explicitly incorporated. Thus, the final numerical value of the peak ground acceleration or duration on the hazard map depends not only on the seismicity of the region, the probability of exceedence and the time period for which the maps are drawn, but also on the uncertainty in the attenuation laws used.

- With the available information of the ground motion duration a hazard map for duration can be developed. Such an "iso-duration" map could be useful in determining the damage potential for a given region. Currently, engineers do not use this parameter explicitly in designing their structures. However, it is felt that the duration of the strong motion is an important parameter. Some combination of the peak ground acceleration information from the iso-acceleration map with the duration information from the iso-duration map may increase the correlation of the estimated damage potential with the earthquake severity.

From the second part of this study, where a parameter study of the 97 accelerograms is conducted, the following conclusions can be drawn:

- For the input accelerograms as well as the response acceleration time histories, the probability distribution function for the amplitudes is either gamma or exponential. If one assumes that the exponential shape is adequate, various useful and practical observations can be made.
- There is no standard definition of a duration of an earthquake or of its response even though the importance of this parameter is widely recognized in earthquake engineering. The definition presented in this dissertation is somewhat arbitrary. However it is an essential step to evaluate parameters such as RMS, ENGY, K_1 and K_2.

- It is shown that the RMS is a better and more stable measure of earthquake ground motion than the currently used peak values. This should be expected since the RMS is a statistical summary and takes into account all the peaks and the duration of the motion. This is true for either input accelerograms or for the response time histories. Also, the uncertainty in RMS is much smaller than the uncertainty in the peak values. Hence the RMS response spectrum is much "smoother" than the conventional response spectrum. This observation has many practical implications.
- Since the peaks of the input or the response time histories have an exponential distribution, the ratio $K_1 = a_p/RMS$ is a constant and only depends on the value of p. This is proved conclusively by analyzing 97 accelerograms. This observation can be very effectively used for practical applications. As an example, assume that one wishes to obtain a design acceleration spectrum which has probability p of being exceeded. Then, the first step would be to obtain, for the region, an RMS response spectrum for a given damping. As mentioned previously, this step should be more reliable and easier than the current method of obtaining a design response spectrum shape. Having obtained the RMS response spectrum, the constant K_1 for a given p can be used to map the RMS response spectrum to the design response spectrum with probability p of exceedence. This is a simple and elegant way of obtaining a probabilistic design spectrum.

- Since it is also observed that the parameter K_2 is a constant for the 97 accelerograms considered, it can be used to a great advantage. Any future energy related design methodology can be correlated to the current response spectra related design method by the use of K_1 and K_2. However, it should confessed at this time that no detailed practical applications of K_2 are presented in this dissertation. The purpose of this overall study is to explore various different ways of hazard mapping and data analysis. The practical applications and possible usage can only be inferred after further research.

6.3 Recommendations for Future Work

During the development of this work, various shortcomings in definitions and in current usage were observed. In spite of those shortcomings, some parameters are used based on current practice. For a better utilization of the methodology presented in this study, the following parameters and ideas need further research.

- Sensitivity analysis of the Bayesian model to source location, seismicity description, type of subjective information and uncertainty in attenuation relations.
- Use of Bayesian model with no historical data
- Development of hazard maps for RMS acceleration, velocity and displacement. This would be a truly useful step towards a better overall design methodology.
- A detailed study of the two stable parameters K_1 snd K_2 before their practical applications can be assessed.

- A better definition of the input and response duration is a must. Without a standard and rational definition of duration one cannot obtain a reliable description of the earthquake or its damage potential.
- A better understanding of the energy in input and response time histories. This may help in developing energy based design methods.

Before the ideas presented in this dissertation can be used or implemented, the above suggested work must be completed. Hopefully, at that time, a better way of developing design load criteria will be made available through the application of the work such as the one presented here.

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APPENDIX A

LISTING OF EARTHQUAKES

A3-2

EARTHQUAKES SORTED BY SOURCES
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(THE FIRST DIGIT OF MAGNITUDES MB,MS OR RICHTER CORRESPOND TO UNIT)

* BENIOFF 5 TO 39 KM (159)

DATA SOURCE	DAY	MONTH	YEAR	HOUR	MINUTE	SECOND	LATITUDE	LONGITUDE		MB MAG			MS MAG		RICHTER MAG		RICHTER MAG
NOS 45	18	06	71	13	36	01	14.678N	87.567W	7	500MB		072	0		0	022	478
CGS-8	30	01	67	09	30	27	12.196N	87.596W	8	410MB		074	0		0	010*	329
CGS 54	15	08	69	01	43	11	09.473N	83.863W	9	440MB		078	0		0	022	379
CGSPDE	14	07	68	03	55	24	15.237N	88.843W	14	450MB		072	0	F	0	033	395
CGS 15	25	02	69	02	31	44	15.274N	87.564W	13	480MB		072	0		0	G036	445
CGS 15	25	02	69	07	39	00	15.231N	87.466W	15	540MB		072	50MS	F	0	G072	500
CGS 77	16	10	68	06	08	45	13.893N	88.250W	16	430MB	4	073	0	F	0	009	362
CGS-8	15	06	64	11	13	47	12.600N	88.000W	14	410MB		076	0		0	005	329
CGSPDE	23	06	67	13	30	46	12.900N	87.800W	11	420MB		074	0		0	012	345
CGSPDE	13	11	67	16	05	46	10.400N	85.700W	18	460MB		078	0		0	019	412
CGSPDE	14	03	68	10	09	19	12.000N	86.800W	25	450MB		075	0		0	013	395
CGS 23	19	03	69	19	49	22	11.786N	88.087W	23	470MB		076	0		0	021	428
EPL 65	02	11	72	18	24	45	11.711N	87.935W	24	460MB		074	0		0	020*	412
CGS-8	20	08	64	08	26	52	11.700N	87.200W	25	430MB		074	0		0	008	362
EPL 71	11	12	72	12	51	04	11.403N	87.151W	27	440MB		074	0		0	0017*	379
CGS-8	23	06	65	07	37	46	11.400N	87.800W	24	450MB		074	0		0	028	395
CGS-8	31	05	65	20	46	54	11.100N	86.000W	28	470MB		074	0		0	030	428
CGSPDE	11	08	67	12	26	18	11.800N	85.900W	21	470MB		075	0		0	017	428
CGSPDE	03	10	67	18	16	03	10.900N	85.900W	21	580MB		078	0		0	104	611
CGS-8	19	11	66	16	01	46	09.200N	85.800W	25	430MB		077	0		0	012	362
EPL 74	25	12	72	00	26	28	15.215N	88.943W	34	460MB		072	0		0	020	412
CGSPDE	04	10	67	00	12	12	15.700N	88.600W	33	440MB		072	0		0	010	379
CGS-8	13	03	66	21	46	23	14.200N	88.400W	36	420MB		072	0		0	017	345
CGS-8	09	01	64	18	38	10	14.900N	87.900W	33	470MB		072	0		0	035	428
CGS 16	08	02	69	06	56	59	13.624N	88.271W	33	430MB	4	073	0	F	0	N006	362
CGS-8	29	10	64	12	21	52	13.200N	88.500W	33	400MB		073	0		0	008	312
CGS-8	24	04	66	15	41	03	13.700N	88.300W	33	390MB		073	0		0	009	300
CGSPDE	06	11	67	18	49	26	13.500N	88.000W	33	430MB		073	0		0	010	362
CGS-8	27	11	64	10	55	11	13.400N	86.700W	33	410MB		073	0		0	006	329
CGSPDE	03	04	68	00	06	00	12.200N	88.300W	33	430MB		076	0		0	011	362
CGS-8	23	08	66	06	07	36	12.400N	88.200W	39	400MB		076	0		0	011	312
CGS-8	15	08	64	14	43	03	12.000N	88.000W	39	400MB		076	0		0	006	312
CGS-8	16	04	66	13	21	40	12.330N	88.400W	33	440MB		076	0		0	017	379
CGS 6*	01	10	69	08	41	31	12.084N	88.358W	33	440MB	3	076	0	F	0	N011	379
CGS-8	12	01	65	03	19	10	12.300N	88.900W	39	430MB		076	0		0	007	362
CGS-3	29	04	64	08	08	41	12.100N	88.400W	33	390MB		076	0		0	007	300
CGS-8	08	05	67	14	40	08	12.974N	88.073W	33	460MB		073	0	F	0	N030	412
CGSPDE	19	09	68	00	37	17	12.143N	88.714W	33	440MB		076	0		0	N014*	379
EPL 47	04	08	73	11	54	16	12.140N	88.983W	33	440MB		076	0		0	N008*	379
CGS-8	30	07	65	06	33	30	12.000N	88.500W	33	420MB		076	0		0	009	345
CGS-8	07	11	64	01	36	56	12.000N	88.000W	33	440MB		076	0		0	012	379
CGS-8	16	12	63	06	23	20	12.200N	88.400W	34	430MB		076	0		0	010	362
CGS-8	21	11	65	02	19	12	12.100N	88.900W	33	430MB		076	0		0	008	362
CGS 41	23	04	69	20	46	40	12.410N	88.052W	33	470MB		076	0		0	N033	428
CGS-8	12	04	66	17	30	49	12.600N	88.000W	33	440MB		076	0		0	019	379
CGS-8	12	04	67	04	56	25	12.217N	88.102W	33	480MB		076	0		0	N025	445
CGS-8	03	12	64	14	51	10	12.300N	88.500W	33	410MB		076	0		0	010	329
CGS-8	23	03	65	02	58	39	12.300N	88.200W	33	410MB		076	0		0	008	329

A3-3

DATA SOURCE	DAY	MONTH	YEAR	HOUR	MINUTE	SECOND	LATITUDE	LONGITUDE		MB MAG		MS MAG		RICHTER MAG		RICHTER MAG
CGSPDE	01	04	68	07	28	28	12.400N	88.500W	33	440MB	076	0		0	013	379
CGS-8	06	11	63	21	49	57	12.200N	88.000W	37	410MB	076	0		0	010	329
CGS-8	24	07	66	18	50	54	12.200N	88.700W	33	410MB	076	0		0	010	329
CGS-8	15	04	67	22	10	08	12.743N	88.163W	33	430MB	076	0		0	N006*	362
CGS-8	16	08	64	12	34	34	12.000N	88.600W	33	430MB	076	0		0	011	362
CGS-8	27	09	65	17	37	53	12.900N	88.400W	33	420MB	076	0		0	007	345
CGS-8	10	12	65	17	59	11	12.400N	87.300W	33	420MB	074	0		0	011	345
CGS-8	08	09	63	05	28	37	12.300N	87.900W	31	410MB	074	0		0	008	329
EPL 30	07	05	73	11	54	36	12.344N	87.949W	33	430MB	074	40MS		0	N013	400
EPL 58	26	09	72	03	20	16	12.231N	87.412W	37	460MB	074	38MS		0	016*	380
CGS 38	13	05	69	16	39	27	12.447N	87.830W	33	420MB	074	0		C	N007*	345
CGS-8	27	06	65	13	08	28	12.600N	87.900W	33	410MB	074	0		0	007	329
CGS-8	02	04	64	03	48	59	12.500N	87.800W	32	420MB	074	0		0	009	345
ISS	20	11	52	15	37	17	12.100N	87.500W	33	0	074	0		625PAS		625
CGS-8	17	06	64	09	11	42	12.000N	87.200W	33	410MB	074	0		0	008	329
CGS-8	23	12	66	22	10	25	12.600N	87.700W	32	450MB	074	0		0	019	395
CGS 48	05	07	70	05	42	05	12.561N	87.446W	33	450MB	074	0		0	N031	395
GS 51	27	07	73	08	51	11	12.415N	87.407W	33	450MB	074	0		0	N017*	395
CGS-8	24	04	65	13	25	41	12.700N	82.000W	33	440MB	094	0		0	009	379
CGS-8	16	07	65	10	34	12	11.600N	88.000W	30	490MB	076	0		0	022	462
CGS-8	23	03	65	17	18	29	11.800N	88.200W	33	420MB	076	0		0	006	345
CGS-8	18	04	67	08	24	17	11.419N	88.415W	33	400MB	076	0		0	N007*	312
NOS 45	16	06	71	04	18	56	11.722N	88.222W	33	450MB	076	0		0	N012*	395
CGS-8	18	06	65	09	28	21	11.600N	88.200W	33	430MB	076	0		0	007	362
EPL 66	27	08	71	09	21	57	11.839N	88.884W	33	500MB	076	38MS		0	N041	380
CGSPDE	28	04	68	10	03	31	11.800N	88.800W	39	490MB	076	0		0	039	462
CGS-8	29	01	67	20	11	22	11.953N	88.928W	33	450MB	076	0		0	N018	395
CGS-8	28	05	66	14	34	39	11.900N	88.100W	33	430MB	076	0		0	013	362
CGS-8	18	07	64	20	37	35	11.000N	87.000W	33	460MB	074	0		0	010	412
CGS-8	29	04	64	21	53	15	11.800N	87.600W	33	450MB	074	0		0	007	395
CGS-8	09	04	65	15	09	15	11.400N	87.400W	33	420MB	074	0		0	009	345
CGS-8	14	04	66	06	57	45	11.800N	87.500W	33	410MB	074	0		0	007	329
CGSPDE	04	07	67	13	29	04	11.600N	87.200W	33	420MB	074	0		0	010	345
CGS-8	22	03	65	00	17	27	11.900N	87.900W	33	430MB	074	0		0	007	362
CGS-8	16	07	65	11	21	10	11.600N	87.800W	33	480MB	074	0		0	016	445
CGS-8	04	10	64	06	30	14	11.300N	87.400W	33	420MB	074	0		0	007	345
CGSPDE	04	07	67	07	39	20	11.800N	87.300W	38	400MB	074	0		0	016	312
NOS 80	25	11	70	05	38	12	11.745N	87.920W	36	480MB	074	0		0	014*	445
NOS 9	11	01	71	17	13	48	11.714N	87.794W	33	480MB	074	0	F	0	N014*	445
CGS 3	06	01	69	09	44	41	11.410N	87.232W	33	430MB	074	0		0	011	362
CGS 3	06	01	69	09	24	23	11.440N	87.245W	33	480MB	074	43MS		0	N026	430
CGS-8	06	06	65	08	34	17	11.100N	87.200W	33	460MB	074	0		0	005	412
CGS-8	30	07	63	12	25	39	11.400N	87.300W	33	420MB	074	0		0	005	345
CGS-8	29	08	64	20	51	54	11.400N	87.200W	33	420MB	074	0		0	005	345
CGS-8	20	08	64	09	12	53	11.000N	87.500W	33	420MB	074	0		0	008	345
CGS-8	13	04	63	18	53	18	11.700N	87.800W	33	430MB	074	0		0	016	362
CGS-8	20	05	67	23	42	19	11.653N	86.714W	33	420MB	074	0		0	N012*	345
CGS-8	08	06	65	01	25	59	11.000N	86.800W	33	470MB	074	0		0	007	428
CGS 92	16	11	68	15	14	37	11.082N	86.911W	33	460MB	074	39MS		0	N018	390
CGS 8	15	01	70	16	57	47	11.614N	86.929W	33	480MB	074	0		0	N038*	445
CGSPDE	02	10	67	15	59	43	11.700N	86.800W	39	470MB	074	0		0	025	428
CGS-8	12	09	64	19	05	47	11.200N	86.900W	33	470MB	074	0		0	014	428
CGS 89	21	11	68	07	19	34	11.203N	86.891W	33	450MB	074	0		0	N016	395
CGS-8	23	03	65	21	21	52	11.000N	86.600W	33	480MB	074	0		0	014	445
CGS-8	30	04	64	15	05	57	11.200N	86.700W	33	430MB	074	0		0	005	362
CGS 54	19	11	68	00	09	27	11.336N	86.714W	33	460MB	074	41MS		0	N022	410
CGS 26	20	03	70	21	00	08	10.428N	87.364W	34	440MB	077	43MS		0	013*	430
CGS 54	20	07	70	04	58	05	10.366N	87.400W	33	460MB	077	0		0	N015*	412
CGS 55	12	08	70	11	07	59	10.867N	87.229W	33	450MB	077	0		0	N039*	395
CGS 37	25	05	70	23	05	18	10.738N	86.939W	33	480MB	077	0		0	N014	445

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CGS 62	02	05	70	17	51	35	10.432N	86.015W	33	430MB		077	0		0	N039*	362
CGS 39	13	05	69	14	36	16	10.817N	86.338W	33	450MB		077	0		0	N008*	395
ERL 10	06	02	72	10	05	31	10.592N	86.400W	36	440MB		077	0		0	038*	379
CGSPDE	25	06	67	22	52	12	10.700N	86.000W	33	400MB		077	0		0	007	312
CGSPDE	04	07	67	06	12	57	10.800N	86.400W	33	410MB		077	0		0	016	329
CGS-B	28	07	64	01	54	18	10.800N	86.200W	33	420MB		077	0		0	006	345
CGS-B	07	07	64	09	59	19	10.800N	86.600W	33	490MB		077	0		0	010	462
CGS-B	17	07	65	04	05	16	10.100N	86.500W	33	430MB		077	0		0	006	362
CGSPDE	04	10	67	06	02	16	10.700N	86.000W	33	530MB		077	0		0	.066	528
ERL 81	14	10	71	06	59	10	10.824N	86.268W	33	470MB		077	40MS		0	N020*	400
CGS-B	13	01	65	02	19	49	10.100N	86.300W	33	480MB		077	0		0	009	445
CGS-B	30	07	64	15	13	39	10.600N	86.500W	33	470MB		077	C		0	037	428
CGS-B	28	09	63	05	25	03	10.200N	86.000W	33	410MB		077	0		0	008	329
CGSPDE	03	10	67	19	22	39	10.400N	86.200W	33	450MB		077	0		0	019	395
CGS-B	14	12	66	01	33	13	10.600N	86.800W	33	430MB		077	0		0	008	362
CGS-B	02	08	64	04	00	45	10.900N	86.300W	32	470MB		077	0		0	012	428
ERL 15	19	02	72	19	41	33	10.674N	86.085W	33	470MB		077	0		0	N014*	428
CGS-B	07	06	65	07	41	47	10.400N	86.000W	33	470MB		077	0		0	037	428
CGS 45	11	07	69	07	51	04	10.342N	85.369W	33	500MB		078	0	F	450BRK	N049	450
CGS-B	16	01	67	15	30	47	10.641N	85.920W	33	470MB		078	0		0	N019*	428
CGS 46	11	07	69	05	57	12	10.189N	85.484W	30	470MB		078	0	F	0	025	428
ERL 36	14	04	73	09	19	09	10.260N	85.015W	33	430MB		078	0		0	N006*	362
CGS-B	15	05	64	12	10	25	10.500N	85.700W	33	450MB		078	0		0	024	395
ERL 71	13	09	71	15	33	27	09.973N	87.361W	33	440MB		077	0		0	N007	379
ERL 77	28	09	71	05	47	16	09.821N	86.267W	33	500MB		077	0		0	N036*	478
CGS-B	15	02	65	02	29	48	09.900N	86.500W	33	550MB		077	0		0	011	561
CGS-B	31	08	64	17	07	39	09.600N	85.400W	33	420MB		077	0		0	036	345
CGS-B	23	02	66	01	02	01	09.700N	85.800W	35	400MB		077	0		0	008	312
CGS-B	15	05	64	05	46	32	09.800N	85.500W	33	420MB		077	0		0	010	345
CGS-B	09	09	65	12	43	37	09.600N	85.300W	33	450MB		077	0		0	008	395
CGS	20	02	54	02	00	43	11.500N	87.500W	N	0		074	0	F	587PAS	*	587
CGS	15	02	54	00	40	25	11.500N	87.500W	N	0		074	0	F	663PAS	*	663
GUTE	22	12	34	14	29	31	11.500N	87.000W	N	0		074	0		650PAS	*	650
GUTE	12	01	33	01	17	42	11.000N	87.000W	N	0		074	0		560PAS	*	560
DEM 238	13	8	58				11.70	87.20	N	D						***	538
DEM 239	3	9	58				11.70	87.20	N	E						***	351
DEM 302	28	9	62				11.60	87.20	N	E						***	457
DEM 335	16	9	63				11.80	87.40	N	E						***	518
GUTE	08	10	41	04	22	13	10.500N	86.250W	0	0		077	0		575PAS	*	575
ISS	11	11	50	13	51	10	10.400N	85.700W	0	0		078	0		575PAS	*	575
DEM 245	21	2	59				11.70	87.20		D						*	582
DEM 248	2	4	59				11.70	87.20		D						*	571
DEM 184	28	12	54				11.50	87.50		E						*	515
DEM 186	11	1	55				11.00	86.50		E						*	498
DEM 203	16	8	55				11.00	87.00		E						*	464
DEM 259	11	9	59				12.00	87.50		E						*	513
DEM 307	15	1	63				12.00	87.50	20	D						***	582
DEM 317	30	6	63				11.40	87.30	33	4.2						***	4.2
DEM 218	19	5	57				12.14	87.24	24	E						*	413
DEM 306	15	1	63				12.00	87.50	33	0						*	589
DEM 298	17	7	62				11.60	87.10	25	E						*	470

* BENIOFF AND COSTA RICA 40 TO 79 KM (186)

CGS 11	31	01	70	22	23	37	15.727N	88.750W	46	500MB		072	45MS		0	060	450
CGS-B	10	11	63	07	18	07	12.900N	88.500W	45	420MB		076	0		0	037	345
CGS-B	24	05	63	06	10	09	12.100N	88.500W	42	440MB		076	0		0	012	379
CGS-B	08	07	66	13	22	13	12.400N	88.900W	43	430MB		076	0		0	013	362
CGS-B	24	01	66	03	46	57	12.300N	88.400W	46	450MB		076	0		0	018	395
CGS 40	06	06	69	16	16	01	12.457N	88.000W	48	500MB	3	076	45MS	F	0	051	450
CGS 90	28	11	68	13	44	33	12.451N	88.006W	49	490MB		076	0		0	021	462

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ERL 85	26	11	71	04	06	38	12.148N	87.626W	47	440MB		074	0		0	013	379
CGS-B	30	01	62	08	34	23	12.700N	87.500W	49	0		074	0	F	488PAL	049	488
CGS-B	04	04	64	06	43	20	12.500N	87.700W	41	430MB		074	0		0	012	362
CGS-B	06	12	65	13	19	13	12.400N	87.400W	44	390MB		074	0		0	007	300
CGS 12	12	02	70	17	22	11	12.139N	86.616W	44	440MB		075	0		0	013	379
ERL 16	05	03	72	21	47	26	11.971N	87.914W	46	460MB	3	074	0	F	0	020*	412
CGS-B	31	08	63	13	08	46	11.900N	87.000W	48	490MB		074	0		0	018	462
CGS-B	08	12	64	04	11	53	11.500N	87.000W	48	500MB		074	0		0	029	478
GS 52	14	07	73	07	55	08	11.637N	87.291W	46	490MB		074	44MS		0	024*	440
ERL 39	28	05	73	06	19	00	11.474N	87.266W	42	460MB		074	40MS		0	014*	400
ERL 42	05	07	73	08	08	07	11.949N	87.541W	48	430MB		074	0		0	015	362
CGS 7	20	01	70	08	27	48	11.482N	86.353W	46	540MB		074	0		0	063	545
CGS-B	12	10	66	20	20	06	11.200N	86.200W	45	510MB		074	0		0	054	495
ERL 9	30	01	72	22	25	03	11.042N	86.750W	43	450MB		074	38MS		0	017	380
CGSPDE	20	06	67	11	42	33	11.000N	86.600W	44	450MB		074	0		0	022	395
CGS-B	30	07	64	05	16	03	11.100N	86.200W	42	570MB		074	0		0	022	594
ERL 7	30	01	72	19	10	07	11.261N	86.773W	49	460MB		074	44MS		0	027	440
CGS 36	13	05	69	17	38	28	11.784N	86.179W	46	490MB		074	52MS		400BRK	042	520
ERL 61	01	10	72	05	00	51	11.015N	86.330W	49	420MB		074	0		0	006*	345
SYKES	27	10	57	18	29	10	15.970N	88.110W	56	0		093	0		400PAL	008	400
CGS 55	03	08	69	21	17	16	13.342N	88.342W	52	430MB		073	0		0	010*	362
CGS 59	04	09	69	06	25	28	13.216N	88.429W	53	460MB	4	073	0	F	0	020	412
ERL 51	31	08	72	02	24	09	13.272N	88.513W	50	540MB		073	48MS		0	058	480
CGSPDE	06	05	68	21	23	11	13.021N	87.734W	56	460MB		072	0		0	0024*	412
CGS-B	25	02	63	08	58	43	12.300N	88.200W	58	410MB		076	0		0	029	329
CGS-B	05	03	64	14	30	18	12.100N	88.100W	53	430MB		076	0		0	009	362
CGS-B	15	06	64	09	41	24	12.600N	88.300W	56	410MB		076	0		0	007	329
CGS-B	19	06	64	17	31	56	12.400N	88.100W	53	400MB		076	0		0	011	312
CGSPDE	18	04	68	04	40	38	12.500N	88.600W	54	490MB		076	0		0	019	462
CGS-B	30	08	64	15	20	50	12.600N	88.500W	54	460MB		076	0		0	015	412
CGS-B	04	07	63	01	43	20	12.800N	88.700W	55	410MB		076	0		0	007	329
CGS-B	13	07	66	08	20	58	12.600N	87.800W	56	530MB		074	0		0	073	528
CGS-B	09	05	63	15	03	43	12.400N	87.000W	50	550MB		074	0		C	047	561
CGS-B	17	07	65	13	59	46	12.200N	87.900W	56	440MB		074	0		0	013	379
CGS-B	27	03	67	14	40	13	12.221N	87.712W	54	420MB		074	0		0	019	345
CGS-B	06	12	65	04	39	10	12.500N	87.300W	50	450MB		074	0		0	024	395
CGS 54	07	08	70	13	03	14	12.325N	87.791W	59	450MB		074	0		0	016	395
NCS 21	25	02	71	04	15	41	12.159N	87.489W	52	530MB		074	0		0	075	528
CGS-B	10	06	64	16	25	09	12.000N	87.900W	55	420MB		074	0		0	006	345
ERL 41	07	07	73	07	07	55	11.842N	87.761W	55	430MB		074	0		0	015	362
CGS 32	24	04	69	22	29	46	11.539N	87.022W	50	440MB		074	0		0	022	379
ERL 40	06	07	73	05	21	49	11.962N	87.588W	51	480MB		074	0		0	023	445
CGS-B	07	10	63	03	59	54	11.600N	86.900W	50	450MB		074	0		0	015	395
ERL 9	04	02	72	01	07	43	11.213N	86.891W	52	480MB		074	0		0	019	445
CGS 23	18	03	70	23	17	57	10.984N	86.015W	56	490MB		074	0		0	037	462
CGS-B	01	03	65	15	17	45	10.800N	86.700W	55	490MB		077	0		0	009	462
CGS-B	18	04	67	07	05	08	10.749N	86.777W	53	480MB		077	0		0	041	445
CGS-B	03	02	64	01	46	27	13.000N	88.000W	61	410MB		073	0		0	006	329
CGS	27	06	58	05	44	28	13.000N	88.500W	60	0		073	0		DF600PAS		600
CGS 80	22	10	68	06	42	01	13.208N	88.247W	64	470MB	5	073	0		0	017	428
CGS-B	20	12	63	22	28	31	13.200N	88.000W	64	430MB		073	0		0	005	362
CGS-B	21	07	64	07	01	59	13.100N	88.400W	68	470MB		073	0		0	030	428
CGS-B	16	08	64	07	30	12	13.300N	87.600W	60	390MB		072	0		0	005	300
CGS-B	02	03	64	16	09	46	12.500N	88.000W	63	440MB		076	0		0	018	379
CGS-B	19	05	61	09	25	41	12.800N	88.200W	68	0	5	076	0	F	463PAL		463
ERL 49	19	08	73	22	17	49	12.651N	88.507W	68	510MB	4	076	0	F	0	0033	495
ERL 14	04	03	72	22	04	23	12.933N	88.743W	64	470MB	4	076	0	F	0	024	428
ERL 15	07	03	73	13	00	45	12.705N	88.027W	64	460MB		076	0		0	013*	412
CGS-B	24	07	66	06	11	55	12.200N	88.300W	61	410MB		076	0		0	013	329
ERL 81	08	11	71	04	26	16	12.472N	88.165W	68	490MB		076	0		0	031	462

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CGSPDE	26	01	68	10	37	56	12.730N	88.800W	60	390MB		076	0		0	007	300
CGS-8	31	07	66	19	10	46	12.400N	88.100W	63	420MB		076	0		0	032	345
CGS-8	04	05	65	18	13	55	12.500N	87.700W	68	510MB		074	0		0	036	495
CGS-8	08	08	64	15	45	10	12.500N	87.600W	63	580MB		074	0		0	032	611
CGS 20	10	03	69	08	15	08	12.349N	87.455W	62	530MB		074	0		600BRK	059	600
CGS-8	21	02	64	07	24	08	12.800N	87.900W	62	390MB		074	0		0	007	300
EFL 85	25	11	71	22	06	26	12.759N	87.458W	62	490MB		074	0		0	024	462
CGS-8	18	04	67	08	29	12	11.731N	87.307W	65	460MB		074	0		0	028	412
ERL 8	16	01	72	23	55	10	11.505N	87.582W	62	460MB		074	0		0	014	412
GUTE	06	C1	41	09	48	34	11.750N	86.500W	60	0		074	0		600PAS		600
CGS-8	20	03	61	06	16	21	11.300N	86.500W	60	0		074	0	F	613PAS		613
CGS 38	14	05	69	13	49	03	11.518N	86.154W	62	480MB		074	0		0	046	445
YDS 44	10	06	71	11	20	31	11.101N	86.766W	60	490MB		074	0		0	015*	462
YDS 30	26	04	71	18	32	20	11.422N	86.760W	69	470MB		074	0		0	040	428
CGS-8	02	11	65	22	44	41	10.500N	86.300W	69	450MB		077	0		0	010	395
CGS-8	C8	03	67	23	07	02	15.131N	88.782W	76	420MB		072	0		0	036*	345
CGS-8	08	03	67	15	52	15	13.049N	88.127W	75	390MB		073	0		0	005*	300
CGS 19	09	03	69	07	12	39	13.101N	88.528W	75	440MB		073	0		0	021	379
GUTE	26	12	39	11	55	11	13.250N	88.250W	75	0		073	0		600PAS	AAA	600
CGS-8	09	01	67	22	31	22	13.138N	88.981W	78	410MB		073	0		0	008	329
CGS-8	04	01	67	00	28	07	13.100N	88.625W	72	410MB		073	0		0	010	329
CGS-8	27	12	66	21	22	16	13.300N	88.800W	78	540MB		073	0		0	090	545
ERL 66	19	11	72	04	35	24	12.973N	88.524W	73	560MB		073	0		0	065	578
CGS-8	10	08	64	14	00	51	12.400N	88.300W	71	400MB		076	0		0	006	312
CGS 33	03	05	69	03	19	06	12.987N	88.449W	77	450MB	5	073	0	F	0	032	395
CGS 25	01	04	69	21	19	53	12.677N	88.233W	71	490MB	4	076	0	F	0	038	462
CGS 26	08	04	69	19	41	58	12.670N	88.340W	76	480MB		076	0		0	023	445
ERL 32	30	04	72	10	55	19	12.896N	88.668W	77	440MB	3	076	0	F	0	019	379
CGS 62	06	09	70	20	44	49	12.783N	88.595W	75	450MB		076	0	F	0	017	395
CGS 34	21	04	70	05	37	08	12.947N	87.880W	79	520MB		074	0		0	045	511
ERL 47	28	07	73	20	48	24	12.333N	87.084W	79	540MB		074	0	F	0	0087	545
CGS-8	22	03	67	09	15	29	12.653N	87.823W	70	440MB		074	0		0	025	379
CGS 71	23	09	70	23	57	45	12.021N	87.446W	70	450MB		074	0		0	029	395
CGS-8	20	10	65	23	54	30	12.530N	87.300W	72	540MB		074	0		0	053	545
CGS-8	25	03	67	07	26	37	12.406N	87.876W	76	400MB		074	0		0	005*	312
CGS-8	25	08	64	05	03	18	12.100N	87.700W	72	400MB		074	0		0	005	312
CGSPDE	28	01	68	08	47	20	12.630N	87.900W	75	440MB		074	0		0	022	379
CGS-8	31	12	63	14	22	07	12.430N	87.900W	77	430MB		074	0		0	007	362
CGSPDE	24	03	68	17	13	20	12.500N	86.500W	79	510MB		075	0		0	043	495
CGS 38	13	05	69	14	15	52	11.438N	86.369W	71	480MB		074	0		0	037	445
CGS 38	13	05	69	14	16	52	11.469N	86.355W	79	560MB		074	0	F	570BRK	104	570
CGS 38	13	05	69	18	11	39	11.523N	86.509W	72	460MB		074	0		0	037	412
CGS 4	15	01	69	06	57	22	11.338N	86.813W	72	450MB		074	0		0	010	395
CGS 8	15	01	70	16	52	42	11.512N	86.733W	70	510MB	3	074	0	F	575BRK	046	575
CGS	19	02	54	21	34	41	12.500N	87.500W	N	0		074	0	F	663PAS	*	663
GUTE	28	03	21	07	49	22	12.500N	87.500W	N	0		074	0		730PAS	*	730
CGS	25	10	56	05	21	40	12.000N	87.000W	N	0		074	0	F	637PAS	*	637
ISS	24	10	56	14	42	12	11.790N	86.460W	N	0		074	0	DF	730PAS	*	730
ISS	24	C4	59	09	31	33	11.430N	86.400W	N	0		074	0		638PAS	*	638
DEM 113	1	5	16				11.00	85.50	N	D						***	547
DEP 114	23	9	16				11.00	85.50	N	D						***	560
DEM 255	12	7	59				11.50	86.00	N	D						***	547
DEM 313	26	2	63				12.40	87.40	N	E						***	505
DEP 326	13	10	63				12.50	87.10	N	D						***	535
DEM 337	23	11	63				12.00	87.20	N	C						***	605
DEM 331	11	3	64				12.50	87.10	N	D						***	540
DEP 332	29	4	64				12.30	87.40	N	E						***	515
DEM 457	13	4	73				10.50	85.50	N	6.7						***	6.7
DEM 111	27	02	16				11.00	85.50	N	C						*	650
DEM 156	30	4	55				12.00	87.00	N	6.0						*	6.0

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DEM 201	7	7	55				12.50	88.00	N	E					*	515
DEM 206	13	10	55				12.00	87.00		E					*	358
DEM 258	15	8	59				12.20	87.30	N	D					*	557
DEP 144	20	2	40				12.50	87.50		C					*	681
DEM 139	25	4	38				12.20	86.90		C					*	676
DEP 141	9	2	39				11.10	86.20		E					*	446
DEP 147	5	8	44				12.50	87.50		E					*	425
DEM 157	2	4	51				12.00	87.00		E					*	419
DEP 158	6	5	51				11.00	85.50		E					*	353
DEM 173	12	3	52				11.00	86.00		E					*	389
DEM 179	21	2	54				11.90	87.00		E					*	480
DEM 182	27	11	54				12.00	87.00		E					*	373
DEM 204	29	8	55				12.00	87.00		E					*	458
DEM 208	21	4	56				12.00	87.33		D					*	581
DEP 247	31	3	59				13.00	87.00		E					*	482
DEP 245	22	4	59				11.50	86.50		D					*	591
DEM 252	30	5	59				11.00	86.00		E					*	448
DEP 262	21	1	60				12.00	87.25		E					*	420
DEM 264	15	2	60				12.00	87.00		E					*	390
DEM 322	9	8	63				12.90	87.40	80	E					***	383
DEP 369	24	5	68				12.50	86.50	79	5.1					***	5.1
DEM 154	13	11	49				11.00	85.50	60	E					*	384
DEM 260	19	11	59				12.00	87.00	60	E					*	397
DEM 263	26	1	60				13.00	87.50	60	D					*	580
DEM 267	10	7	60				12.50	86.00	150	6.0					*	6.0
DEM 289	22	12	61				11.90	85.50	49	E					*	393
DEP 311	11	2	63				11.60	87.50	41	E					*	496
DEM 314	25	4	63				12.20	87.30	75	E					*	415
DEP 180	21	2	54				12.50	87.00	60	E					*	420
DEP 241	14	11	58				12.36	86.37	72	C					*	670
CGS-8	01	10	63	10	30	31	10.200N	84.500W	46	460MB	078	0		0	022	412
CGS-8	30	12	66	18	35	15	10.100N	84.700W	43	440MB	078	0		0	015	379
CGS-8	02	05	64	19	53	10	09.500N	84.500W	44	430MB	078	0		0	007	362
CGS-8	09	04	66	02	42	11	09.530N	84.100W	49	570MB	078	0		0	079	594
CGS-8	20	06	64	05	02	37	09.200N	84.400W	45	430MB	078	0		0	007	362
CGS-8	C9	04	66	02	34	23	09.400N	84.200W	47	530MB	078	0		0	071	528
CGS-8	16	10	65	14	22	55	09.000N	83.500W	48	510MB	078	0		0	053	495
CGS-8	28	03	66	00	33	30	09.500N	83.100W	46	400MB	078	0		0	008	312
CGS-8	17	07	66	00	14	03	09.200N	82.300W	44	400MB	080	0		0	013	312
CGS 31	16	04	70	C5	04	41	09.632N	84.240W	50	430MB	078	0		0	G014*	362
CGS 53	05	08	70	13	22	05	09.841N	84.317W	56	460MB	078	0		0	023	412
CGS-8	15	1G	64	21	09	02	09.600N	84.000W	51	420MB	078	0		0	007	345
ISS	13	05	52	19	31	45	10.300N	85.300W	64	0	078	0		690PAS		690
CGS-8	13	10	63	05	10	12	09.800N	84.100W	63	440MB	078	0		0	012	379
CGS-8	27	03	66	23	12	49	09.800N	83.300W	61	420MB	078	0		0	018	345
CGS-8	02	07	63	18	05	33	09.330N	83.000W	64	420MB	078	0		0	011	345
CGS-8	13	05	67	12	48	00	09.247N	82.395W	68	400MB	080	0		0	008*	312
CGS-8	21	06	63	03	32	41	10.730N	85.800W	73	500MB	078	0		0	022	478
GUTE	18	04	39	16	46	05	10.030N	83.000W	70	0	078	0		650PAS	8C8	650
CGS-8	01	05	66	22	28	45	09.600N	83.900W	71	430MB	078	0		0	018	362
GUTE	26	C4	16	02	21	30	10.330N	85.000W	0	0	078	0		730PAS	*	730
GUTE	21	12	39	20	54	48	10.000N	85.000W	0	0	078	0		730PAS	*	730
GUTE	06	12	41	01	25	01	10.500N	85.250W	0	0	078	0		600PAS	*	600
GUTE	22	12	39	04	44	00	10.000N	84.500W	0	0	078	0		675PAS	*	675
ISS	09	09	52	12	54	42	09.200N	84.200W	0	0	078	0	F	688PAS	*	688
GUTE	05	10	40	14	38	43	09.500N	84.250W	0	0	078	0		625PAS	*	625
GUTE	27	10	40	05	35	37	09.750N	84.500W	0	0	078	0		675PAS	*	675
CGS	19	07	56	23	26	25	09.530N	84.500W	0	0	078	0	F	600BRK	*	600
GUTE	04	03	24	10	07	42	09.750N	84.000W	0	0	078	0		700PAS	*	700

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* BENIOFF 80 TO 109 KM (72)																		
GUTE	16	11	41	09	39	46	13.250N	88.500W	80	0			073	0		575PAS	AAA	575
CGS-8	20	09	66	03	53	34	13.100N	88.200W	81	400MB			073	0		0	008	312
CGS-8	13	11	64	08	02	38	13.000N	88.600W	66	490MB			073	0		0	024	462
ERL 11	17	02	72	09	19	06	13.269N	88.691W	80	470MB		5	073	0	F	0	031	428
CGS-8	24	02	64	02	29	12	13.000N	87.200W	83	390MB			072	0		0	036	300
CGS-8	05	07	63	14	40	54	12.830N	88.900W	85	410MB			076	0		0	011	329
CGS-8	23	12	66	02	02	19	12.900N	88.600W	88	450MB			076	0		0	023	395
CGSPDE	06	12	67	02	53	06	12.530N	87.200W	87	530MB			074	0		0	057	528
CGS 48	26	07	69	07	21	00	12.625N	87.798W	84	480MB			074	0		0	039	445
CGS-8	18	04	67	13	05	15	12.765N	87.943W	84	390MB			074	0		0	037*	300
CGS-8	01	08	64	08	55	49	11.800N	87.000W	88	430MB			074	0		0	008	362
CGS-8	23	04	67	14	44	10	11.525N	86.480W	82	440MB			074	0		0	014	379
GUTE	07	03	31	00	41	56	11.500N	85.500W	80	0			075	0		600PAS	ACB	600
CGS-8	10	12	66	01	09	39	10.300N	85.100W	87	430MB			078	0		0	011	362
CGS-8	19	07	65	22	14	21	10.600N	85.300W	80	460MB			078	0		0	019	412
NGS 31	01	05	71	14	32	12	13.259N	88.499W	93	540MB		5	073	0	F	0	053	545
CGS-8	16	03	64	06	06	51	13.500N	88.300W	92	390MB			073	0		0	008	300
ISS	06	05	51	23	03	32	13.000N	87.800W	96	0			072	0		625TAC		625
GUTE	08	07	39	21	31	44	12.500N	88.000W	90	0			076	0		550PAS	CCC	550
CGS-8	09	02	66	06	22	44	12.700N	87.800W	98	440MB			074	0		0	021	379
CGS-8	20	10	65	23	54	51	12.700N	87.000W	91	560MB			074	0		0	032	578
GUTE	21	05	32	10	10	07	12.000N	87.500W	90	0			074	0		690PAS	AAA	690
CGS-8	23	05	64	06	45	21	11.700N	86.600W	93	460MB			074	0		0	037	412
ISS	26	02	52	15	39	28	11.500N	86.300W	96	0			074	0	F	600PAS		600
ISS	27	10	56	15	33	02	11.880N	86.460W	90	0			074	0		587PAS		587
CGS-8	04	07	64	02	36	54	11.330N	86.500W	90	410MB			074	0		0	007	329
TAC	13	01	54	00	26	30	14.000N	86.416W	100	0			072	0		575TAC		575
CGS 31	04	04	69	08	43	06	13.534N	88.981W	105	430MB			073	0		0	038*	362
GUTF	07	02	31	03	30	35	13.000N	87.000W	100	0			072	0		575PAS	CCC	575
CGS-8	06	03	64	02	55	11	12.400N	87.600W	100	390MB			074	0		0	008	300
CGS-8	12	04	66	03	34	22	12.600N	87.600W	104	390MB			074	0		0	009	300
CGS-8	03	09	64	01	55	32	12.200N	87.000W	108	400MB			074	0		0	005	312
CGS	03	05	59	04	41	24	12.530N	87.500W	100	0		5	074	0	F	560TAC		560
ERL 40	27	06	72	14	45	32	12.182N	86.588W	104	460MB			075	0		0	014*	412
CGS-8	01	07	64	00	42	55	12.000N	86.700W	108	430MB			075	0		0	038	362
NOS 75	03	11	70	08	39	12	11.664N	86.112W	100	460MB			074	0		0	0023	412
ERL 73	14	12	72	03	55	41	11.858N	86.574W	104	460MB			074	0		0	0019*	412
CGS 42	24	06	69	00	35	05	11.661N	85.717W	100	530MB			075	0		500PAL	G035	500
CGS	10	11	56	00	08	27	10.500N	86.000W	100	0			077	0		600PAS		600
CGS	04	04	55	19	24	04	13.000N	87.000W	N	0			072	0		625PAS	*	625
DEM 310	16	1	63				13.00	86.70	N	E							***	367
DEM 328	21	12	63				13.40	87.20	N	D							***	570
DEP 207	24	1	56				12.20	66.70	I	7.3							*	7.3
DEP 137	12	1	37				12.58	87.16		D							*	590
DEM 243	27	12	58				12.80	87.30		D							*	593
DEP 135	1	9	35				12.58	87.16		E							*	465
DEM 138	25	9	37				11.00	85.00		E							*	444
DEM 152	25	1	49				11.00	86.00		E							*	429
DEP 190	10	3	55				12.50	87.00		E							*	486
DEM 195	30	4	55				12.50	87.00		D							*	597
DEM 216	28	1	57				12.00	86.50		E							*	486
DEP 235	4	6	58				12.00	86.50		E							*	352
DEM 148	5	10	45				13.00	87.00	100	E							*	365
DEM 153	11	6	49				12.50	87.00	100	E							*	397
DEP 155	11	5	51				13.00	87.50	100	E							*	467
DEM 169	17	12	51				11.50	86.30	96	E							*	375
DEM 171	2	3	52				11.50	86.30	100	D							*	572
DEP 183	2	12	54				12.00	86.50	100	E							*	497
DEM 226	26	11	57				11.50	86.50	100	E							*	512

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DEM 242	4	12	58				11.50	86.50	100	6.0							*	6.0
DEP 290	8	1	62				12.20	85.40	103	E							*	380
DEP 292	17	1	62				11.90	86.30	97	E							*	389
DEM 303	27	10	62				11.60	86.40	106	E							*	360
ISS	16	02	59	17	54	15	13.110N	87.340W	0	0			072	0		540TAC	*	540
ISS	06	05	51	23	08	01	13.000N	87.800W	0	0			072	0		CD650TAC	*	650
ISS	07	05	51	20	22	21	13.000N	87.800W	0	0			072	0		600TAC	*	600
GUTE	07	03	34	22	41	47	13.250N	87.750W	0	0			072	0		625PAS	*	625
GUTE	29	06	19	23	14	23	13.500N	86.500W	90	0			075	0		675PAS	8CC	675
DEM 130	21	5	33				12.00	87.50	90	6.9	OFL						***	6.9
DEM 334	11	5	63				11.40	87.50	100	0	OFL						***	542
DEM 413	24	9	69				11.66	87.71	100	5.3	OFL						***	5.3
* BENIOFF 110 TO 159 KM (31)																		
CGS-8	28	08	63	05	55	51	12.600N	87.200W	115	420MB			074	0		0	006	345
CGS-8	17	08	64	19	05	44	12.400N	86.800W	116	450MB			075	0		0	008	395
CGS-8	30	04	67	03	10	49	12.632N	86.852W	115	420MB			075	0		0	009	345
CGS-8	02	11	64	07	07	57	11.800N	86.900W	117	460MB			074	0		0	009	412
CGS-8	28	07	64	02	53	26	11.500N	86.400W	111	420MB			074	0		0	006	345
CGS-8	12	04	61	22	20	33	13.200N	88.900W	122	0		6	073	0	D	588PAS		588
CGS-8	07	08	66	04	11	30	11.000N	86.200W	125	410MB			074	0		0	009	329
CGS-8	01	09	63	22	57	34	11.300N	85.500W	120	440MB			075	0		0	010	379
CGSPDE	07	07	68	19	49	36	14.678N	88.939W	134	450MB			072	0		0	017*	395
CGS-8	23	05	61	16	44	59	12.700N	87.300W	138	0		6	074	0	DF	650PAS		650
CGS-8	21	01	65	20	43	55	12.300N	86.700W	138	440MB			075	0		0	016	379
GUTE	05	10	25	04	09	07	12.250N	85.250W	135	0			075	0		675PAS	BBA	675
GUTE	05	11	26	07	55	38	12.300N	85.800W	135	0			075	0		700PAS	BBA	700
CGS-8	07	08	64	08	21	03	11.800N	86.900W	130	470MB			074	0		0	010	428
CGS-8	12	08	64	12	47	46	11.400N	86.100W	135	410MB			074	0		0	007	329
CGSPDE	14	07	67	18	02	08	13.500N	88.800W	147	460MB			073	0		0	014	412
CGS-8	17	09	63	03	48	09	12.600N	87.100W	144	390MB			074	0		0	007	300
NOS 41	11	06	71	11	51	40	12.647N	86.967W	148	450MB			074	0		0	024*	395
CGS-8	24	04	64	14	40	28	13.300N	88.800W	158	510MB			073	0		0	044	495
CGSPDE	20	08	68	00	34	04	13.105N	87.833W	157	430MB			072	0		0	014	362
CGS-8	16	12	65	05	23	06	12.600N	88.800W	152	440MB			076	0		0	019	379
CGS-8	06	03	67	23	31	25	12.339N	87.127W	159	410MB			074	0		0	008*	329
CGS	03	05	54	17	13	32	12.000N	86.000W	150	0			075	0		600PAS		600
CGSPDE	28	01	68	18	20	49	12.100N	86.900W	152	440MB			075	0		0	015	379
GUTE	22	07	19	22	01	35	12.000N	85.000W	150	0			075	0		650PAS	CCC	650
DEM 209	9	8	56				12.80	86.00	N	D							***	571
DEM 300	16	8	62				12.60	85.60	N	D							***	562
DEM 246	15	3	59				12.00	85.00		E							*	386
DEM 393	28	12	68				12.10	86.90	152	4.4							***	4.4
DEM 231	23	12	57				12.50	86.50	150	E							*	368
DEP 265	3	5	61				12.20	86.90	124	E							*	381
* BENIOFF 160 TO 215 KM (41)																		
CGS 74	15	09	68	04	32	04	13.456N	87.243W	164	390MB			072	0		0	039*	300
ERL 22	09	04	73	03	17	48	12.267N	86.553W	167	470MB			075	0		0	035	428
CGSPDE	15	10	67	08	00	50	11.930N	86.000W	162	620MB			074	0		0	083	677
CGS-8	02	07	63	22	00	48	13.700N	88.900W	173	410MB			073	0		0		329
NOS 16	19	02	71	16	59	40	13.562N	88.795W	176	520MB		3	073	0	F	0	0042	511
CGS 51	17	07	69	13	24	22	12.590N	87.006W	175	440MB			074	0		0	G012	379
CGS-8	01	07	65	16	57	30	12.100N	87.500W	176	430MB			074	0		0	007	362
GUTE	26	01	47	10	06	46	12.500N	86.250W	170	0			075	0		720PAS	8BA	720
CGS 21	14	03	69	08	47	16	12.916N	86.755W	178	560MB		4	075	0	F	580PAS	D109	580
CGS 22	27	03	70	18	39	18	12.631N	86.823W	182	510MB			075	0		0	031	495
CGSPDE	27	08	67	13	08	55	12.300N	86.200W	183	520MB			075	0		0	060	511
CGS-8	30	06	66	10	39	00	11.900N	85.900W	187	400MB			075	0		0	021	312
CGS 68	06	10	70	15	18	54	13.561N	88.312W	192	460MB			073	0		0	018*	412

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                                                                       A3-10
CGSPDE    11 06 68 05 52 33 13.941N 88.761W 199 530MB          073 0        0   0056  528
ERL 49    27 07 73 19 42 47 12.813N 86.674W 199 530MB    3     075 0   F    0   0111  528
CGSPDE    01 03 68 16 34 44 11.700N 85.500W 190 480MB          075 0        0    033  445
CGS 67    29 09 70 04 42 46 11.473N 85.479W 192 540MB          075 0   540BRK   D132  540
CGS-B     01 07 66 20 17 49 11.700N 88.400W 201 460MB          073 0        0    049  412
CGS-B     09 12 64 14 22 03 13.200N 87.200W 200 390MB          072 0        0    008  300
ERL 45    28 07 72 13 53 40 13.151N 87.753W 209 440MB          072 0        0   J16*  379
CGS-B     25 07 66 00 42 58 13.230N 87.800W 210 400MB          072 0        0    006  312
ERL 60    12 08 71 05 59 00 12.977N 87.341W 211 470MB          074 0        0    026  428
CGS-B     19 01 67 02 19 23 12.561N 86.613W 200 450MB          075 0        0   G024  395
GUTE      24 02 34 05 33 30 12.750N 86.750W 200   0            075 0   600PAS   A38   600
GUTE      07 04 44 13 32 58 12.000N 85.500W 200   0            075 0   600PAS   8CC   600
CGS 11    29 01 70 23 06 39 11.492N 86.086W 215 480MB          074 0        0   G018* 445
GUTE      24 04 16 08 02 12 11.030N 85.000W   N   0            075 0    730PAS    *   730
GUTF      05 10 50 16 09 31 11.000N 85.000W   N   0            075 0  C0770PAS    *   770
DEM 301 10  9 62                12.30   86.70   N   E                             *   370
DEM 121 25 10 28                12.30   85.80       C                             *   622
DEM 162  9  7 51                11.03   85.00       E                             *   466
DEP 189  7  3 55                13.00   87.00       E                             *   394
DEM 194 11  4 55                13.53   87.00       E                             *   506
DEM 265 24  3 60                13.50   87.00       E                             *   368
DEP 266 26  4 60                11.03   84.50       E                             *   493
ISS       28 09 51 12 07 07 11.530N 86.300W  20 0   0          07 4 0    575PAS   *   575
DEM 168 28  9 51                11.50   86.30  160      E                         *   466
DEP 274 22  3 61                11.80   86.80  172      E                         *   449
DEM 118 10  2 22                13.00   85.40    1      C  CFL                    *   671
DEM 143 29 12 39                13.00   86.00           E  OFL                    *   521
DEM 299 24  7 62                11.20   87.70  173      E  OFL                    *   390

* COSTA RICA  5 TO 39 KM  (23)
CGS-B     26 07 64 13 53 25 11.830N 88.200W   9 440MB          076 0        0    010  379
NOS 41    05 06 71 14 20 42 09.339N 84.232W  26 540MB    3    T078 51MS F   0    082  510
ERL 47    04 08 73 00 44 42 09.838N 84.586W  33 530MB          078 54MS F 520BRK N083  540
ERL 60    05 08 71 22 58 08 09.541N 84.069W  33 490MB          078 0        0   N019  462
CGS-B     27 03 64 17 12 36 09.200N 84.000W  33 420MB          078 0        0    011  345
CGS-B     13 04 65 04 46 43 09.700N 84.400W  33 400MB          078 0        0    006  312
CGS-B     15 10 64 21 04 11 09.130N 84.000W  36 430MB          078 0        0    011  362
CGS-B     20 02 64 09 54 12 09.500N 84.600W  33 430MB          078 0        0    009  362
ERL 13    26 02 73 00 43 39 09.606N 84.229W  33 470MB          078 40MS F   0   N031  400
CGS-B     17 12 65 04 03 28 09.300N 84.200W  35 420MB          078 0        0    007  345
GUTE      09 03 37 15 40 20 09.330N 83.500W  30   0            078 0    640PAS        640
CGS-B     09 08 66 11 12 39 09.300N 83.800W  35 470MB          078 0        0    032  428
CGS-B     27 03 64 17 27 35 09.430N 83.900W  33 420MB          078 0        0    015  345
ERL 13    23 02 73 19 36 48 09.845N 83.493W  33 470MB          078 42MS     0   N038  420
CGS-B     21 07 66 13 53 23 09.100N 83.900W  33 400MB          078 0        0    011  312
CGS-B     10 07 66 19 18 57 09.700N 83.900W  33 410MB          078 0        0    008  329
CGS-B     15 10 64 22 52 35 09.600N 83.700W  37 420MB          078 0        0    011  345
CGS-B     31 07 63 18 33 28 09.200N 82.400W  33 410MB          080 0        0    006  329
CGS-B     02 04 64 15 25 41 09.500N 82.700W  33 390MB          080 0        0    007  300
CGSPDE    02 07 68 16 15 48 09.065N 82.934W  33 420MB          080 0        0   N007* 345
CGS-B     12 11 65 08 59 54 10.000N 84.400W  37 500MB          078 0        0    037  478
ERL 34    14 04 73 08 54 29 10.711N 84.763W  33 480MB          078 0        0   N034* 445
ERL 36    14 04 73 08 34 00 10.679N 84.759W  33 570MB          078 65MS C0650PAS N117* 650

* COSTA RICA AREA  80 TO 119 KM  (10)
CGS-B     11 12 66 17 21 55 10.230N 84.100W  62 430MB          078 0        0    018  362
ERL 11    25 02 72 03 43 47 10.187N 83.414W  88 460MB          078 0        0   019*  412
GUTE      19 11 48 01 04 24 10.030N 83.500W  80   0            078 0    700PAS   88C   700
CGS-B     11 08 66 09 50 41 10.500N 84.000W  96 430MB          078 0        0    J14  362
CGS-B     23 05 61 03 40 24 09.830N 84.000W  93   0            078 0    538PAL        538
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CGS-B     23 05 67 17 14 50 10.197N 84.022W 119 430MB          078 0        0   008*  362
CGSPDE    04 07 68 15 15 59 10.464N 84.056W 113 440MB          078 0        0    012  379
CGS-B     23 07 64 04 57 54 10.500N 83.900W 114 420MB          078 0        0    010  345
CGS-B     12 08 63 17 19 05 09.830N 84.200W 114 420MB          078 0        0    007  345
DEM 160 18  6 51                11.00   84.00   96   E                            *   449
* PACIFIC COASTLINE  33 KM  (12)
CGS 55    12 08 70 09 24 11 12.015N 86.542W  33 590MB          075 63MS F 600PAS N077  630
CGS-B     11 05 66 05 57 02 12.300N 86.800W  33 400MB          075 0        0    037  312
CGS 55    12 08 70 10 24 23 12.051N 86.539W  33 560MB          075 55MS  530PAS N057  550
ERL 12    15 02 73 00 15 53 11.534N 86.473W  33 510MB          074 50MS     0   0053  500
CGSPDE    08 10 67 14 28 07 11.300N 86.000W  33 420MB          074 0        0    009  345
CGS-B     21 03 65 09 42 41 11.700N 86.400W  36 520MB          074 0        0    036  511
CGS  8    15 01 70 19 08 59 11.157N 86.015W  33 460MB          074 0        0   N012* 412
ERL 73    29 08 71 08 26 52 11.567N 86.180W  "3 490MB          074 0        0   N034  462
ERL 77    24 08 71 08 09 07 11.539N 86.323W  33 510MB          074 42MS     0   N049  420
DEM 172  3  3 52                11.50   86.30   33   E                            *   500
DEM 174  5 12 52                11.50   86.30   33   E                            *   486
DEM 253  5  6 59                12.06   86.52   27   E                            *   491

* ATLANTIC ALL DEPTH  (11)
CGS-B     25 06 62 18 58 35 14.500N 82.400W  25   0            094 0    463PAL   015  463
CGS-B     20 05 66 03 58 01 11.600N 82.600W  33 390MB          079 0        0    009  300
CGS-B     11 08 65 18 15 39 10.800N 83.200W  33 390MB          078 0        0    007  300
CGS-B     08 10 66 20 38 07 10.700N 82.400W  33 410MB          079 0        0    008  329
GUTE      17 03 26 11 53 36 12.530N 82.500W  50   0            094 0    690PAS        690
GUTF      06 12 37 21 43 09 14.000N 82.000W  60   0            094 0    600PAS        600
CGSPDE    17 07 68 06 23 11 10.394N 83.349W  19 510MB          078 0        0   0052  495
CGSPDE    03 03 68 08 43 24 10.000N 83.100W  16 410MB          078 0        0    010  329
GUTE      20 03 36 18 46 28 11.030N 84.000W   N   0            075 0    560PAS    *   560
GUTE      25 07 13 12 38 06 13.000N 83.000W   0   0            075 0    630PAS    *   630
SYKES     07 12 57 22 18 51 13.550N 82.410W   0   0            094 0    510PAL   023  510

* PARAGLA VOLCANO LINE   N  (57)
CGS-B     09 05 63 15 06 24 12.700N 86.600W  33 410MB          075 0        0    008  329
ERL  2    05 01 72 11 52 26 12.256N 86.236W  33 420MB          075 0        0   N019* 345
ERL  1    03 01 72 04 31 04 12.311N 86.300W  33 410MB          075 0        0   N019* 329
DEM 131 11  7 33                12.20   86.30    N   D                           ***  583
DEM 132 24  8 33                12.20   86.30    N   D                           ***  531
DEM 156  5  1 51                12.20   86.30    N   D                           ***  565
DEP 272 16  2 61                12.70   86.50   40   E                            *   393
DEM 309 15  1 63                13.00   86.70   33   E                            *   444
DEP 141  8  7 51                12.03   86.00        E        DEEP M AY BE        *   489
DEM 175     1 53                13.50   86.50        D        DEEP M AY BE        *   576
DEP 200 30  4 55                12.50   86.50        D        DEEP M AY BE        *   559
DEM 236  5  6 58                12.50   86.50        E        DEEP M AY BE        *   461
DEM 256 12  8 59                12.00   86.00        E        DEEP M AY BE        *   470
DEP  41       50                12.60   86.36    N   D  V                        ***  598
DEM  42 11  4 50                12.48   86.68    N   C  V                        ***  674
DEM  43 27  4 50                12.48   86.67    N   D  V                        ***  551
DEM  44       52                12.42   86.55    N   D  V                        ***  561
DEM  45  8  5 52                12.16   86.30    N   C  V                        ***  692
DEM  46 29  6 52                11.95   86.15    N   D  V                        ***  566
DEP  47     7 52                11.95   86.15    N   D  V                        ***  575
DEM  49  8  4 53                11.95   86.15    N   D  V                        ***  547
DEM  50 29  6 53                11.95   86.15    N   D  V                        ***  595
DEM  51     5 53                11.95   86.15    N   D  V                        ***  595
DEM  53  2  1 55                11.95   86.15    N   D  V                        ***  560
DEM      2  1 55                11.95   86.15    N   D  V                        ***  595
DEM  54    12 56                11.95   86.15    N   C  V                        ***  682
DEM  55       56                11.95   86.15    N   C  V                        ***  653
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DEM 56			57				11.95	86.15	N	C	V				***	632
DEM 57	11	4	58				11.95	86.15	N	C	V				***	661
DEM 58	25	4	58				11.95	86.15	N	C	V				***	656
DEM 59			58				12.42	86.55	N	D	V				***	552
DEM 60	10	11	58				11.95	86.15	N	C	V				***	644
DEM 61	27	1	59				11.95	86.15	N	C	V				***	680
DEM 62	27	3	59				11.95	86.15	N	D	V				***	581
DEM 64			60				11.95	86.15	N	D	V				***	585
DEM 67		8	63				12.70	87.02	N	D	V				***	568
DEM 69	14	11	67				12.48	86.68	N	B	V				***	729
DEM 70	24	7	68				12.42	86.55	N	C	V				***	670
DEM 71	16	6	70				11.95	86.15	N	C	V				***	689
DEM 72	18	6	70				12.42	86.55	N	C	V				***	674
DEM 82		4	83				11.53	85.65	N	D	V				***	574
DEM 83		5	83				11.53	85.65	N	D	V				***	546
DEM 84	2	5	83				11.53	85.65	N	D	V				***	557
DEM 85	4	5	83				11.53	85.65	N	D	V				***	539
DEM 86	6	5	83				11.53	85.65	N	D	V				***	530
DEM 87	6	5	83				11.53	85.65	N	D	V				***	564
DEM 88	15	5	83				11.53	85.65	N	D	V				***	542
DEM 101	22	5	86				12.42	86.55	N	C	V				***	628
DEM 109	1	5	11				11.50	85.70	N	D	V				***	592
DEM 110	17	10	13				11.95	86.15	N	D	V				***	557
DEM 149	11	2	46				11.63	85.60		C	V				***	696
DEM 151	15	7	47				12.50	86.80	N	C	V				***	643
DEM 358	24	10	68				12.52	86.73	N	C	V				***	611
DEM 428	3	2	71				12.53	86.70	N	D	V				***	581
DEM 431	3	5	71				12.70	87.00	N	D	V				***	581
DEM 428	1	12	71				12.63	86.90	N	D	V				***	585
* MANAGUA AREA 5 KM (5)																
ERL 77	23	12	72	07	19	49	12.030N	86.189W	5	520MB		075	0	0	G049	511
CGSPUE	04	01	68	10	03	56	12.100N	86.300W	5	460MB		075	0	0	328	412
ERL 76	23	12	72	06	29	42	12.357N	86.119W	5	560MB		075	62MS	CD620PAS	G099	620
ERL 77	23	12	72	07	17	36	12.050N	86.378W	5	500MB		075	0	0	G029	478
GUTE	31	03	31	16	02	21	12.250N	86.200W	0	0		075	0	560PAS	*	560
* FONSECA AREA 33 KM (8)																
DEM 329	18	2	64				13.00	87.50	N	D					***	546
DEM 304	24	11	62				13.00	87.50	25	C					***	615
DEM 284	29	8	61				13.00	87.50	33	D					*	562
DEM 254	16	6	62				13.30	87.30	33	E					*	369
DEM 166	6	8	51				13.33	87.50	33	5.5					*	550
ISS	03	08	51	00	23	58	13.000N	87.800W	33	0		072	0	DF600PAS		600
ISS	03	08	51	05	25	44	13.030N	87.800W	33	0		072	0	550PAS		550
ISS	02	08	51	20	30	17	13.030N	87.800W	33	0		072	0	575PAS		575

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EARTHQUAKES IN CHRONOLOGICAL ORDER
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(THE FIRST DIGIT OF MAGNITUDES MB,MS OR RICHTER CORRESPOND TO UNIT)

DATA SOURCE	DAY	MONTH	YEAR	HOUR	MINUTE	SECOND	LATITUDE	LONGITUDE		MB MAG			MS MAG	RICHTER MAG		RICHTER MAG
DEM 41			50				12.60	86.36	N	D	V				***	598
DEM 42	11	4	50				12.48	86.68	N	C	V				***	674
DEM 43	27	4	50				12.48	86.67	N	D	V				***	551
DEM 44			52				12.42	86.55	N	D	V				***	561
DEM 45	8	5	52				12.16	86.30	N	C	V				***	692
DEM 46	29	6	52				11.95	86.15	N	D	V				***	566
DEM 47		7	52				11.95	86.15	N	D	V				***	575
DEM 49	8	4	53				11.95	86.15	N	D	V				***	547
DEM 50	29	6	53				11.95	86.15	N	D	V				***	595
DEM 51		9	53				11.95	86.15	N	D	V				***	595
DEM 53	2	1	55				11.95	86.15	N	D	V				***	540
DEM	2	1	55				11.95	86.15	N	D	V				***	595
DEM 54		12	56				11.95	86.15	N	C	V				***	682
DEM 55			56				11.95	86.15	N	C	V				***	653
DEM 56			57				11.95	86.15	N	C	V				***	632
DEM 57	11	4	58				11.95	86.15	N	C	V				***	661
DEM 58	25	4	58				11.95	86.15	N	C	V				***	656
DEM 59			58				12.42	86.55	N	D	V				***	552
DEM 60	10	11	58				11.95	86.15	N	C	V				***	644
DEM 61	27	1	59				11.95	86.15	N	C	V				***	680
DEM 62	27	3	59				11.95	86.15	N	D	V				***	581
DEM 64			60				11.95	86.15	N	D	V				***	585
DEM 67		8	63				12.70	87.02	N	D	V				***	568
DEM 69	14	11	67				12.48	86.68	N	B	V				***	729
DEM 70	24	7	68				12.42	86.55	N	C	V				***	670
DEM 71	16	6	70				11.95	86.15	N	C	V				***	689
DEM 72	18	6	70				12.42	86.55	N	C	V				***	674
DEM 82		4	83				11.53	85.65	N	D	V				***	574
DEM 83		5	83				11.53	85.65	N	D	V				***	546
DEM 84	2	5	83				11.53	85.65	N	D	V				***	557
DEM 85	4	5	83				11.53	85.65	N	D	V				***	539
DEM 86	6	5	83				11.53	85.65	N	D	V				***	530
DEM 87	6	5	83				11.53	85.65	N	D	V				***	564
DEM 88	15	5	83				11.53	85.65	N	D	V				***	542
DEM 101	22	5	86				12.42	86.55	N	C	V				***	628
DEM 109	1	5	11				11.50	85.70	N	D	V				***	592
GUTE	25	07	13	12	38	06	13.000N	83.000W	0	0		075	0	630PAS	*	630
DEM 110	17	10	13				11.95	86.15	N	D	V				***	557
DEM 113	1	5	16				11.00	85.50	N	D					***	547
DEM 114	23	9	16				11.00	85.50	N	D					***	560
DEM 111	27	02	16				11.00	85.50	N	C					*	650
GUTE	24	04	16	08	02	12	11.000N	85.000W	N	0		075	0	730PAS	*	730
GUTE	26	04	16	02	21	30	10.000N	85.000W	0	0		078	0	730PAS	*	730
GUTE	29	06	19	23	14	23	13.500N	86.500W	90	0		075	0	675PAS	BCC	675
GUTE	22	07	19	22	01	35	12.000N	85.030W	150	0		075	0	650PAS	CCC	650
GUTE	28	03	21	07	49	22	12.500N	87.500W	N	0		074	0	730PAS	*	730
DEM 118	10	2	22				13.00	85.40	I	C	DFL				*	671
GUTE	04	03	24	10	07	42	09.750N	84.000W	0	0		078	0	700PAS	*	700
GUTE	05	10	25	04	09	07	12.250N	85.250W	135	0		075	0	675PAS	BBA	675

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GUTE		17	03	26	11	53	36	12.500N	82.500W	50	0		094	0	690PAS		690
GUTE		05	11	26	07	55	38	12.330N	85.800W	135	0		075	0	700PAS	BBA	700
DEM	121	25	10	28				12.30	85.80		C					*	622
GUTE		07	02	31	03	30	35	13.000N	87.000W	100	0		072	0	575PAS	CCC	575
GUTE		07	03	31	00	41	56	11.530N	85.500W	80	0		075	0	600PAS	AC8	600
GUTE		31	03	31	16	02	21	12.250N	86.200W	0	0		075	0	560PAS	*	560
GUTE		21	05	32	10	10	07	12.030N	87.500W	90	0		074	0	690PAS	AAA	690
DEM	130	21	5	33				12.03	87.50	90	6.9	OFL				***	6.9
DEM	131	11	7	33				12.20	86.30	N	D					***	583
DEM	132	24	8	33				12.20	86.30	N	D					***	531
GUTE		12	01	33	01	17	42	11.030N	87.000W	N	0		074	0	560PAS	*	560
GUTE		24	02	34	05	33	30	12.750N	86.750W	200	0		075	0	600PAS	ABB	600
GUTE		07	03	34	22	41	47	13.250N	87.750W	0	0		072	0	625PAS	*	625
GUTE		22	12	34	14	29	31	11.530N	87.000W	N	0		074	0	650PAS	*	650
DEM	135	1	9	35				12.58	87.16		E					*	465
GUTE		20	03	36	18	46	28	11.000N	84.000W	N	0		075	0	560PAS	*	560
DEM	137	12	1	37				12.58	87.16		D					*	590
DEM	138	25	9	37				11.00	85.00		E					*	444
GUTE		09	03	37	15	40	20	09.000N	83.500W	30	0		078	0	640PAS		640
GUTE		06	12	37	21	43	09	14.000N	82.000W	60	0		094	0	600PAS		600
DEM	139	25	4	38				12.20	86.90		C					*	676
DEP	141	9	2	39				11.10	86.20		E					*	446
GUTE		18	06	39	16	46	05	10.030N	83.000W	70	0		078	0	650PAS	BCB	650
GUTE		08	07	39	21	31	44	12.500N	88.000W	90	0		076	0	550PAS	CCC	550
GUTE		21	12	39	20	54	48	10.030N	85.000W	0	0		078	0	730PAS	*	730
GUTE		22	12	39	04	44	00	10.000N	84.500W	0	0		078	0	675PAS	*	675
GUTE		26	12	39	11	55	11	13.250N	88.250W	75	0		073	0	600PAS	AAA	600
DEM	143	29	12	39				13.00	86.00		E	OFL				*	521
DEM	144	20	2	40				12.50	87.50		C					*	681
GUTE		05	10	40	14	38	43	09.500N	84.250W	0	0		078	0	625PAS	*	625
GUTE		27	10	40	05	35	37	09.750N	84.500W	0	0		078	0	675PAS	*	675
GUTE		06	01	41	09	48	34	11.750N	86.500W	60	0		074	0	600PAS		600
GUTE		08	10	41	04	22	13	10.500N	86.250W	0	0		077	0	575PAS	*	575
GUTE		16	11	41	09	39	46	13.250N	88.500W	80	0		073	0	575PAS	AAA	575
GUTE		06	12	41	01	25	01	10.500N	85.250W	0	0		078	0	600PAS	*	600
DEP	147	5	8	44				12.50	87.50		E					*	425
GUTE		07	04	44	13	32	58	12.030N	85.500W	200	0		075	0	600PAS	BCC	600
DEM	148	5	10	45				13.00	87.00	100	E						365
DEP	149	11	2	46				11.60	85.60		C	V				***	696
DEM	151	15	7	47				12.50	86.80	N	C	V				***	643
GUTE		26	01	47	10	06	46	12.500N	86.250W	170	0		075	0	720PAS	B3A	720
GUTE		19	11	48	01	04	24	10.000N	83.500W	80	0		078	0	700PAS	BBC	700
DEP	152	25	1	49				11.03	86.00		E					*	429
DEM	153	11	6	49				12.50	87.00	100	E					*	397
DEP	154	13	11	49				11.30	85.50	60	E					*	384
GUTE		05	10	50	16	09	31	11.030N	85.000W	N	0		075	0	CO770PAS	*	770
ISS		11	11	50	13	51	10	10.400N	85.700W	0	0		078	0	575PAS	*	575
DEP	156	5	1	51				12.20	86.30	N	D					***	565
DEM	157	2	4	51				12.03	87.00		E					*	419
DEM	158	6	5	51				11.00	85.50		E					*	353
DEP	159	11	5	51				13.00	87.50	100	E					*	467
DEM	160	18	6	51				11.03	84.00	56	E					*	449
DEM	161	8	7	51				12.00	86.00		E		DEEP M AY BE			*	489
DEM	162	9	7	51				11.03	85.00		E					*	466
DEM	166	6	8	51				13.03	87.50	33	5.5					*	550
DEM	168	28	9	51				11.50	86.30	160	E					*	466
ISS		06	05	51	23	08	01	13.000N	87.800W	0	0		072	0	CO650TAC	*	650
ISS		06	05	51	23	03	32	13.000N	87.800W	56	0		072	0	625TAC		625
ISS		07	05	51	20	22	21	13.030N	87.800W	0	0		072	0	600TAC	*	600
ISS		02	08	51	20	30	17	13.000N	87.800W	33	0		072	0	575PAS		575

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ISS		03	08	51	05	25	44	13.330N	87.800W	33	0		072	0	550PAS		550
ISS		03	08	51	00	23	58	13.000N	87.900W	33	0		072	0	DF600PAS		600
ISS		28	09	51	12	07	07	11.500N	86.300W	20	0	0	074	0	575PAS	*	575
DEM	169	17	12	51				11.50	86.30	96	E					*	375
DEM	171	2	3	52				11.53	86.30	100	D					*	572
DEM	172	3	3	52				11.50	86.30	33	E					*	500
DEP	173	12	3	52				11.03	86.00		E					*	389
ISS		26	02	52	15	39	28	11.530N	86.300W	96	0		074	0	F 600PAS		600
ISS		13	05	52	19	31	45	10.330N	85.300W	64	0		078	0	690PAS		690
ISS		09	09	52	12	54	42	09.200N	84.200W	0	0		078	0	F 688PAS	*	688
ISS		20	11	52	15	37	17	12.130N	87.900W	33	0		074	0	625PAS		625
DEM	174	5	12	52				11.50	86.30	33	E					*	486
DEM	175		1	53				13.50	86.50		D		DEEP M AY BE			*	576
DEM	180	21	2	54				12.53	87.00	60	E					*	420
DEM	179	21	2	54				11.90	87.00		E					*	480
TAC		13	01	54	00	26	30	14.030N	86.416W	100	0		072	0	575TAC		575
CGS		19	02	54	21	34	41	12.530N	87.500W	N	0		074	0	F 663PAS	*	663
CGS		19	02	54	00	40	25	11.500N	87.500W	N	0		074	0	F 663PAS	*	663
CGS		20	02	54	02	00	43	11.530N	87.500W	N	0		074	0	F 587PAS	*	587
CGS		03	05	54	17	13	32	12.000N	86.000W	150	0		075	0	600PAS		600
DEM	182	27	11	54				12.00	87.00		E					*	373
DEM	183	2	12	54				12.03	86.50	100	E					*	497
DEM	184	28	12	54				11.50	87.50		E					*	515
DEM	186	11	1	55				11.00	86.50		E					*	498
DEM	189	7	3	55				13.03	87.00		E					*	394
DEM	190	10	3	55				12.53	87.03		E					*	486
DEM	194	11	4	55				13.50	87.00		E					*	506
DEP	200	30	4	55				12.50	86.50		D		DEEP M AY BE			*	559
DEM	195	30	4	55				12.53	87.00		D					*	597
DEM	196	30	4	55				12.00	87.00	N	6.0					*	6.0
DEM	201	7	7	55				12.50	88.00	N	E					*	515
DEM	203	16	8	55				11.03	87.00		E					*	464
DEM	204	29	8	55				12.00	87.00		E					*	458
CGS		04	04	55	19	24	04	13.030N	87.000W	N	0		072	0	625PAS	*	625
DEM	206	13	10	55				12.03	87.00		E					*	358
DEP	207	24	1	56				12.20	86.70	1	7.3					*	7.3
DEP	208	21	4	56				12.03	87.33		D					*	581
DEM	209	9	8	56				12.83	86.00	N	0					***	571
CGS		19	07	56	23	26	25	09.500N	84.500W	0	0		078	0	F 600BFK	*	600
ISS		24	10	56	14	42	12	11.790N	86.460W	N	0		074	0	DF730PAS	*	730
CGS		25	10	56	05	21	40	12.000N	87.000W	N	0		074	0	F 637PAS	*	637
ISS		27	10	56	15	33	02	11.880N	86.460W	90	0		074	0	587PAS		587
CGS		10	11	56	00	08	27	10.500N	86.000W	100	0		077	0	600PAS		600
DEM	216	28	1	57				12.03	86.50		E					*	486
DEP	218	19	5	57				12.14	87.24	24	E					*	413
SYKES		27	10	57	18	29	10	15.970N	88.110W	56	0		093	0	400PAL	008	400
DEM	226	26	11	57				11.50	86.50	100	E					*	512
SYKES		07	12	57	22	18	51	13.550N	82.410W	0	0		094	0	510PAL	023	510
DEM	231	23	12	57				12.53	86.50	150	E					*	368
DEM	235	4	6	58				12.00	86.50		E					*	352
DEP	236	5	6	58				12.50	86.50		E		DEEP M AY BE			*	461
DEM	238	13	8	58				11.73	87.20	N	D					***	538
DEM	239	3	9	58				11.70	87.20	N	E					***	351
CGS		27	06	58	05	44	28	13.000N	88.500W	60	0		073	0	DF600PAS		600
DEM	241	14	11	58				12.36	86.37	72	C					*	670
DEM	242	4	12	58				11.50	86.50	100	6.0					*	6.0
DEP	243	27	12	58				12.83	87.30		D					*	593
DEM	245	21	2	59				11.70	87.20		D					*	582
DEM	246	15	3	59				12.00	85.00		E					*	384
DEP	247	31	3	59				13.00	87.00		E					*	482

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DEM	248	2	4	59				11.70	87.20		D					*	571
DEM	249	22	4	59				11.50	86.50		D					*	591
DEM	252	30	5	59				11.00	86.00		E					*	448
DEM	253	5	6	59				12.05	86.52	27	E					*	491
DEM	255	12	7	59				11.50	86.00	N	D					***	547
DEM	256	12	8	59				12.00	86.00		E	DEEP M AY BE				*	470
DEM	258	15	8	59				12.20	87.30	N	D					*	557
DEM	259	11	9	59				12.00	87.50		E					*	513
ISS		16	02	59	17	54	15	13.110N	87.340W	0	0		072	0	540TAC	*	540
ISS		24	04	59	09	31	33	11.480N	86.400W	N	0		074	0	638PAS	*	638
CGS		03	05	59	04	41	24	12.530N	87.530W	100	0	5	074	0	F 560TAC		560
DEM	260	19	11	59				12.00	87.00	60	E					*	397
DEM	262	21	1	60				12.00	87.25		E					*	420
DEM	263	26	1	60				13.00	87.50	60	D					*	580
DEM	264	15	2	60				12.00	87.00		E					*	390
DEM	265	24	3	60				13.50	87.00		E					*	368
DEM	266	26	4	60				11.00	84.50		E					*	493
DEM	267	10	7	60				12.50	86.00	150	6.0					*	6.0
DEM	272	16	2	61				12.70	86.50	40	E					*	393
DEM	274	22	3	61				11.80	86.80	172	E					*	449
DEM	284	29	8	61				13.00	87.50	33	D					*	562
DEM	285	3	9	61				12.20	86.90	124	E					*	381
CGS-8		20	03	61	06	16	21	11.300N	86.500W	60	0		074	0	F 613PAS		613
CGS-8		12	04	61	22	20	33	13.200N	88.900W	122	0	6	073	0	D 588PAS		588
CGS-8		19	05	61	09	25	41	12.800N	88.200W	68	0	5	076	0	F 463PAL		463
CGS-8		23	05	61	16	44	59	12.700N	87.300W	138	0	6	074	0	DF650PAS		650
CGS-8		23	05	61	03	40	24	09.800N	84.000W	93	0		078	0	538PAL		538
DEM	289	22	12	61				11.90	85.50	49	E					*	393
DEM	290	8	1	62				12.20	85.40	103	E					*	380
DEM	292	17	1	62				11.90	86.30	97	E					*	389
DEM	294	16	6	62				13.30	87.30	33	E					*	369
DEM	298	17	7	62				11.60	87.10	25	E					*	470
DEM	299	24	7	62				11.20	87.70	173	E	DFL				*	390
DEM	300	16	8	62				12.60	85.60	N	D					***	562
DEM	301	10	9	62				12.30	86.70	N	E					*	370
DEM	302	28	9	62				11.60	87.20	N	E					***	457
CGS-8		30	01	62	08	34	23	12.700N	87.500W	49	0		074	0	F 488PAL	049	488
CGS-8		25	06	62	18	58	35	14.500N	82.400W	25	0		054	0	463PAL	015	463
DEM	303	27	10	62				11.60	86.40	106	E					*	360
DEM	304	24	11	62				13.00	87.50	25	C					***	615
DEM	305	15	1	63				13.00	86.70	33	E					*	444
DEM	306	15	1	63				12.00	87.50	33	D					*	589
DEM	307	15	1	63				12.00	87.50	20	D					***	582
DEM	310	16	1	63				13.00	86.70	N	E					***	367
DEM	311	11	2	63				11.60	87.50	41	E					*	496
DEM	313	26	2	63				12.40	87.40	N	E					***	505
DEM	314	25	4	63				12.20	87.30	75	E					*	415
DEM	334	11	5	63				11.40	87.50	100	D	DFL				***	542
DEM	317	30	6	63				11.40	87.30	33	4.2					***	4.2
DEM	322	9	8	63				12.90	87.40	80	E					***	383
DEM	335	16	9	63				11.80	87.40	N	E					***	518
CGS-8		25	02	63	08	58	43	12.300N	88.200W	58	410MB		076	0	0	029	329
CGS-8		13	04	63	18	53	18	11.700N	87.800W	33	430MB		074	0	0	016	362
CGS-8		09	05	63	15	03	43	12.400N	87.000W	50	550MB		074	C	0	047	561
CGS-8		09	05	63	15	06	24	12.700N	86.600W	33	410MB		075	0	0	006	329
CGS-8		24	05	63	06	10	09	12.100N	88.500W	42	440MB		076	0	0	012	379
CGS-8		21	06	63	03	32	41	10.700N	85.600W	73	500MB		078	0	0	022	478
CGS-8		02	07	63	18	05	33	09.000N	83.000W	64	420MB		078	0	0	011	345
CGS-8		02	07	63	22	00	48	13.700N	88.900W	173	410MB		073	0	0		329
CGS-8		04	07	63	01	43	20	12.800N	88.700W	55	410MB		076	0	0	037	329

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CGS-8		05	07	63	14	40	54	12.800N	88.900W	85	410MB	076	0	0	011	329
CGS-8		30	07	63	12	25	39	11.400N	87.300W	33	420MB	074	0	0	005	345
CGS-8		31	07	63	18	33	28	09.200N	82.400W	33	410MB	080	0	0	006	329
CGS-8		12	08	63	17	19	05	09.900N	84.200W	114	420MB	078	0	0	007	345
CGS-8		28	08	63	05	55	51	12.600N	87.200W	115	420MB	074	0	0	006	345
CGS-8		31	08	63	13	08	46	11.900N	87.000W	48	490MB	074	0	0	018	462
CGS-8		01	09	63	22	57	34	11.300N	85.500W	120	440MB	075	0	0	010	379
CGS-8		08	09	63	05	28	37	12.300N	87.900W	31	410MB	074	0	0	008	329
CGS-8		17	09	63	03	48	09	12.600N	87.100W	144	390MB	074	0	0	007	300
CGS-8		28	09	63	05	25	03	10.200N	86.000W	33	410MB	077	0	0	008	329
CGS-8		01	10	63	10	30	31	10.200N	84.500W	46	460MB	078	0	0	022	412
CGS-8		07	10	63	03	59	54	11.600N	86.500W	50	450MB	074	0	0	015	395
DEM	326	13	10	63				12.50	87.10	N	D				***	535
CGS-8		13	10	63	05	10	12	09.800N	84.100W	63	440MB	078	0	0	012	379
CGS-8		06	11	63	21	49	57	12.200N	88.000W	37	410MB	076	0	0	010	329
CGS-8		10	11	63	07	18	07	12.900N	88.500W	45	420MB	076	0	0	007	345
DEM	327	23	11	63				12.00	87.20	N	C				***	605
CGS-8		16	12	63	06	23	20	12.200N	88.400W	34	430MB	076	0	0	010	362
CGS-8		20	12	63	22	28	31	13.200N	88.000W	64	430MB	073	0	0	005	362
DEM	328	21	12	63				13.40	87.20	N	D				***	570
CGS-8		31	12	63	14	22	07	12.400N	87.900W	77	430MB	074	0	0	007	362
DEM	329	18	2	64				13.00	87.50	N	D				***	546
DEM	331	11	3	64				12.50	87.10	N	D				***	540
DEM	332	29	4	64				12.30	87.40	N	E				***	515
CGS-8		09	01	64	18	38	10	14.900N	87.900W	33	470MB	072	0	0	005	428
CGS-8		03	02	64	01	46	27	13.000N	88.000W	61	410MB	073	0	0	006	329
CGS-8		20	02	64	09	54	12	09.500N	84.600W	33	430MB	078	0	0	009	362
CGS-8		21	02	64	07	24	08	12.800N	87.900W	62	390MB	074	0	0	007	300
CGS-8		24	02	64	02	29	12	13.000N	87.200W	83	390MB	072	0	0	006	300
CGS-8		02	03	64	16	09	46	12.500N	88.000W	63	440MB	076	0	0	018	379
CGS-8		05	03	64	14	30	18	12.100N	88.100W	53	430MB	076	0	0	009	362
CGS-8		06	03	64	02	55	11	12.400N	87.600W	100	390MB	074	0	0	008	300
CGS-8		16	03	64	06	06	51	13.500N	88.300W	92	390MB	073	0	0	008	300
CGS-8		27	03	64	17	27	35	09.400N	83.900W	33	420MB	078	0	0	015	345
CGS-8		27	03	64	17	12	36	09.200N	84.000W	33	420MB	078	0	0	011	345
CGS-8		02	04	64	15	25	41	09.500N	82.700W	33	390MB	080	0	0	007	300
CGS-8		02	04	64	03	48	59	12.500N	87.800W	32	420MB	074	0	0	009	345
CGS-8		04	04	64	06	43	20	12.500N	87.700W	41	430MB	074	0	0	012	362
CGS-8		24	04	64	14	40	28	13.300N	88.800W	158	510MB	073	0	0	044	495
CGS-8		29	04	64	08	08	41	12.100N	88.400W	33	390MB	076	0	0	007	300
CGS-8		29	04	64	21	53	15	11.800N	87.600W	33	450MB	074	0	0	007	395
CGS-8		30	04	64	15	05	57	11.200N	86.700W	33	430MB	074	0	0	005	362
CGS-8		02	05	64	19	53	10	09.500N	84.500W	44	430MB	078	0	0	007	362
CGS-8		15	05	64	05	46	32	09.800N	85.500W	33	420MB	077	0	0	010	345
CGS-8		15	05	64	12	10	25	10.500N	85.700W	33	450MB	078	0	0	024	395
CGS-8		23	05	64	06	45	21	11.700N	86.600W	93	460MB	074	0	0	007	412
CGS-8		10	06	64	16	25	09	12.000N	87.900W	55	420MB	074	0	0	006	345
CGS-8		15	06	64	09	41	24	12.600N	88.300W	56	410MB	076	0	0	007	329
CGS-8		15	06	64	11	13	47	12.600N	88.000W	14	410MB	076	0	0	005	329
CGS-8		17	06	64	09	11	42	12.000N	87.200W	33	410MB	074	0	0	008	329
CGS-8		19	06	64	17	31	56	12.400N	88.100W	53	400MB	076	0	0	011	312
CGS-8		20	06	64	05	02	37	09.200N	84.400W	45	430MB	078	0	0	007	362
CGS-8		01	07	64	00	42	55	12.000N	86.700W	108	430MB	075	0	0	008	362
CGS-8		04	07	64	02	36	54	11.300N	86.500W	90	410MB	074	0	0	007	329
CGS-8		07	07	64	09	59	19	10.800N	86.600W	33	490MB	077	0	0	010	462
CGS-8		18	07	64	20	37	35	11.000N	87.000W	33	460MB	074	0	0	010	412
CGS-8		21	07	64	07	01	59	13.100N	88.400W	68	470MB	073	0	0	030	428
CGS-8		23	07	64	04	57	54	10.500N	83.900W	114	420MB	078	0	0	010	345
CGS-8		26	07	64	13	53	25	11.800N	88.200W	9	440MB	076	0	0	010	379
CGS-8		28	07	64	02	53	26	11.500N	86.400W	111	420MB	074	0	0	006	345

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CGS-8	28	07	64	01	54	18	10.800N	86.200W	33	420MB	077	0	0	006 345
CGS-8	30	07	64	15	13	39	10.600N	86.500W	33	470MB	077	0	0	007 428
CGS-8	30	07	64	05	16	03	11.100N	86.200W	42	570MB	074	0	0	022 594
CGS-8	01	08	64	08	55	49	11.800N	87.000W	88	430MB	074	0	0	008 362
CGS-8	02	08	64	04	00	45	10.930N	86.300W	32	470MB	077	0	0	012 428
CGS-8	07	08	64	08	21	03	11.800N	86.900W	130	470MB	074	0	0	010 428
CGS-8	08	08	64	15	45	10	12.500N	87.800W	63	580MB	074	0	0	032 611
CGS-8	10	08	64	14	00	51	12.400N	88.300W	71	400MB	076	0	0	006 312
CGS-8	12	08	64	12	47	46	11.400N	86.100W	135	410MB	074	0	0	007 329
CGS-8	15	08	64	14	43	03	12.000N	88.000W	39	400MB	076	0	0	036 312
CGS-8	16	08	64	12	34	34	12.030N	88.600W	33	430MB	076	0	0	011 362
CGS-8	16	08	64	07	30	12	13.300N	87.600W	60	390MB	072	0	0	035 300
CGS-8	17	08	64	19	05	44	12.400N	86.800W	116	450MB	075	0	0	008 395
CGS-8	20	08	64	08	26	52	11.700N	87.200W	25	430MB	074	0	0	008 362
CGS-8	20	08	64	09	12	53	11.000N	87.500W	33	420MB	074	0	0	008 345
CGS-8	25	08	64	05	03	18	12.100N	87.700W	72	400MB	074	0	0	035 312
CGS-8	29	08	64	20	51	56	11.600N	87.200W	33	420MB	074	0	0	005 345
CGS-8	30	08	64	15	20	50	12.600N	88.500W	54	460MB	076	0	0	015 412
CGS-8	31	08	64	17	07	39	09.630N	85.400W	33	420MB	077	0	0	036 345
CGS-8	03	09	64	01	55	32	12.200N	87.000W	108	400MB	074	0	0	005 312
CGS-8	12	09	64	19	05	47	11.200N	86.900W	33	470MB	074	0	0	014 428
CGS-8	04	10	64	06	30	14	11.300N	87.400W	33	420MB	074	0	0	007 345
CGS-8	15	10	64	21	09	02	09.600N	84.000W	51	420MB	078	0	0	007 345
CGS-8	15	10	64	21	04	11	09.100N	84.000W	36	430MB	078	0	0	011 362
CGS-8	15	10	64	22	52	35	09.600N	83.700W	37	420MB	078	0	0	011 345
CGS-8	29	10	64	12	21	52	13.200N	88.500W	33	400MB	073	0	0	008 312
CGS-8	02	11	64	07	07	57	11.800N	86.900W	117	460MB	074	0	0	009 412
CGS-8	07	11	64	01	36	56	12.000N	88.000W	33	440MB	076	0	0	012 379
CGS-8	13	11	64	08	02	38	13.000N	88.600W	86	490MB	073	0	0	024 462
CGS-8	27	11	64	10	55	11	13.400N	88.700W	33	410MB	073	0	0	036 329
CGS-8	03	12	64	14	51	10	12.300N	88.500W	33	410MB	076	0	0	010 329
CGS-8	08	12	64	04	11	53	11.500N	87.000W	48	530MB	074	0	0	029 478
CGS-8	09	12	64	14	22	03	13.200N	87.200W	200	390MB	072	0	0	008 300
CGS-8	12	01	65	03	19	10	12.300N	88.900W	39	430MB	076	0	0	007 362
CGS-8	13	01	65	02	19	49	10.100N	86.300W	33	480MB	077	0	0	009 445
CGS-8	21	01	65	20	43	55	12.300N	86.700W	138	440MB	075	0	0	016 379
CGS-8	15	02	65	02	29	46	07.900N	86.500W	33	550MB	077	0	0	011 561
CGS-8	01	03	65	15	17	45	10.830N	86.700W	55	490MB	077	0	0	009 462
CGS-8	21	03	65	09	42	41	11.700N	86.400W	36	520MB	074	0	0	036 511
CGS-8	22	03	65	00	17	27	11.900N	87.900W	33	430MB	074	0	0	007 362
CGS-8	23	03	65	21	21	52	11.000N	86.600W	33	480MB	074	0	0	014 445
CGS-8	23	03	65	02	58	39	12.300N	88.200W	33	410MB	076	0	0	038 329
CGS-8	23	03	65	17	18	29	11.800N	88.200W	33	420MB	076	0	0	006 345
CGS-8	09	04	65	15	09	15	11.400N	87.400W	33	420MB	074	0	0	009 345
CGS-8	13	04	65	04	46	43	09.700N	84.400W	33	400MB	078	0	0	006 312
CGS-8	24	04	65	13	25	41	12.700N	82.000W	33	440MB	094	0	0	009 379
CGS-8	31	05	65	20	46	54	11.100N	86.000W	28	470MB	074	0	0	030 428
CGS-8	06	06	65	08	34	17	11.100N	87.200W	33	460MB	074	0	0	005 412
CGS-8	07	06	65	07	41	47	10.400N	86.000W	33	470MB	077	0	0	007 428
CGS-8	08	06	65	01	25	59	11.000N	86.800W	33	470MB	074	0	0	007 428
CGS-8	18	06	65	09	28	21	11.600N	88.200W	33	430MB	076	0	0	007 362
CGS-8	23	06	65	07	37	46	11.400N	87.800W	24	450MB	074	0	0	028 395
CGS-8	27	06	65	13	08	28	12.600N	87.900W	33	410MB	074	0	0	007 329
CGS-8	01	07	65	16	57	30	12.100N	87.500W	176	430MB	074	0	0	007 362
CGS-8	16	07	65	10	34	12	11.600N	88.000W	30	490MB	076	0	0	022 462
CGS-8	16	07	65	11	21	10	11.600N	87.800W	33	480MB	074	0	0	016 445
CGS-8	17	07	65	04	05	16	10.100N	86.500W	33	430MB	077	0	0	006 362
CGS-8	17	07	65	13	59	46	12.200N	87.900W	56	440MB	074	0	0	013 379
CGS-8	19	07	65	22	14	21	10.600N	85.300W	60	460MB	078	0	0	019 412
CGS-8	30	07	65	06	33	30	12.020N	88.900W	33	420MB	076	0	0	009 345

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CGS-8	11	08	65	18	15	39	10.800N	83.200W	33	390MB	078	0	0	007 300
CGS-8	09	09	65	12	43	37	09.600N	85.300W	33	450MB	077	0	0	008 395
CGS-8	27	09	65	17	37	53	12.900N	88.400W	33	420MB	076	0	0	007 345
CGS-8	16	10	65	14	22	55	09.300N	83.500W	48	510MB	078	0	0	053 495
CGS-8	20	10	65	23	54	51	12.700N	87.000W	91	560MB	074	0	0	032 578
CGS-8	20	10	65	23	54	30	12.500N	87.300W	72	540MB	074	0	0	063 545
CGS-8	02	11	65	22	44	41	10.500N	86.300W	89	450MB	077	0	0	010 395
CGS-8	12	11	65	08	59	54	10.600N	84.400W	37	500MB	078	0	0	037 478
CGS-8	21	11	65	02	19	12	12.100N	88.900W	33	430MB	076	0	0	008 362
CGS-8	06	12	65	13	19	13	12.400N	87.400W	44	390MB	074	0	0	007 300
CGS-8	06	12	65	04	39	10	12.500N	87.300W	50	450MB	074	0	0	024 395
CGS-8	10	12	65	17	59	11	12.400N	87.300W	33	420MB	074	0	0	011 345
CGS-8	16	12	65	05	23	06	12.600N	88.800W	157	440MB	076	0	0	019 379
CGS-8	17	12	65	04	03	28	09.300N	84.200W	35	420MB	078	0	0	007 345
CGS-8	24	01	66	03	46	57	12.300N	88.400W	46	450MB	076	0	0	018 395
CGS-8	09	02	66	06	22	44	12.700N	87.800W	98	440MB	074	0	0	021 379
CGS-8	23	02	66	01	02	01	09.700N	85.800W	35	400MB	077	0	0	008 312
CGS-8	13	03	66	21	46	23	14.200N	88.400W	36	420MB	072	0	0	017 345
CGS-8	27	03	66	23	12	49	09.800N	83.300W	61	420MB	078	0	0	018 345
CGS-8	28	03	66	00	33	30	09.500N	83.100W	46	400MB	078	0	0	008 312
CGS-8	09	04	66	02	34	23	09.400N	84.200W	47	530MB	078	0	0	071 528
CGS-8	09	04	66	02	42	11	09.500N	84.100W	49	570MB	078	0	0	079 594
CGS-8	12	04	66	03	34	22	12.600N	87.600W	104	390MB	074	0	0	009 300
CGS-8	12	04	66	17	30	49	12.600N	88.000W	33	440MB	076	0	0	019 379
CGS-8	14	04	66	06	57	45	11.800N	87.500W	33	410MB	074	0	0	007 329
CGS-8	16	04	66	13	21	40	12.300N	88.400W	33	440MB	076	0	0	017 379
CGS-8	24	04	66	15	41	03	13.700N	88.300W	33	390MB	073	0	0	009 300
CGS-8	01	05	66	22	28	45	09.600N	83.900W	71	430MB	078	0	0	018 362
CGS-8	04	05	66	18	13	55	12.500N	87.700W	68	510MB	074	0	0	036 495
CGS-8	11	05	66	05	57	02	12.300N	86.800W	33	400MB	075	0	0	007 312
CGS-8	20	05	66	03	58	01	11.600N	82.600W	33	390MB	079	0	0	009 300
CGS-8	28	05	66	14	34	39	11.930N	88.100W	33	430MB	076	0	0	013 362
CGS-8	30	06	66	10	39	00	11.930N	85.900W	187	400MB	075	0	0	021 312
CGS-8	01	07	66	20	17	49	13.700N	88.400W	201	460MB	073	0	0	049 412
CGS-8	08	07	66	13	22	13	12.430N	88.900W	43	430MB	076	0	0	013 362
CGS-8	10	07	66	19	18	57	09.700N	83.900W	33	410MB	078	0	0	008 329
CGS-8	13	07	66	08	20	58	12.600N	87.800W	56	530MB	074	0	0	073 528
CGS-8	17	07	66	00	14	03	09.200N	82.300W	44	400MB	080	0	0	013 312
CGS-8	21	07	66	13	53	23	09.100N	83.900W	33	400MB	078	0	0	011 312
CGS-8	24	07	66	06	11	55	12.200N	88.300W	61	410MB	076	0	0	013 329
CGS-8	24	07	66	18	50	54	12.200N	88.700W	33	410MB	076	0	0	010 329
CGS-8	25	07	66	00	42	58	13.230N	87.800W	210	400MB	072	0	0	006 312
CGS-8	31	07	66	19	10	46	12.400N	88.100W	63	420MB	076	0	0	032 345
CGS-8	07	08	66	04	11	30	11.030N	86.200W	125	410MB	074	0	0	009 329
CGS-8	09	08	66	11	12	39	09.300N	83.800W	35	470MB	078	0	0	032 428
CGS-8	11	08	66	09	50	41	10.500N	84.000W	96	430MB	078	0	0	014 362
CGS-8	23	08	66	06	07	36	12.400N	88.200W	39	400MB	076	0	0	011 312
CGS-8	20	09	66	03	53	34	13.100N	88.230W	81	400MB	073	0	0	008 312
CGS-8	08	10	66	20	38	07	10.700N	82.400W	33	410MB	079	0	0	008 329
CGS-8	12	10	66	20	20	06	11.200N	86.200W	45	510MB	074	0	0	054 495
CGS-8	19	11	66	16	01	46	09.200N	85.800W	25	430MB	077	0	0	012 362
CGS-8	10	12	66	01	09	39	10.300N	85.100W	87	430MB	078	0	0	011 362
CGS-8	11	12	66	17	21	56	10.200N	84.100W	82	430MB	078	0	0	018 362
CGS-8	14	12	66	01	33	13	10.600N	86.800W	33	430MB	077	0	0	008 362
CGS-8	23	12	66	22	10	25	12.600N	87.700W	32	450MB	074	0	0	019 395
CGS-8	23	12	66	02	02	19	12.900N	88.600W	88	450MB	076	0	0	023 395
CGS-8	27	12	66	21	22	15	13.300N	88.800W	78	540MB	073	0	0	090 545
CGS-8	30	12	66	18	35	15	10.100N	84.700W	43	440MB	078	0	0	015 379
CGS-8	04	01	67	00	28	07	13.130N	88.625W	72	410MB	073	0	0	010 329
CGS-8	09	01	67	22	31	22	13.138N	88.981W	78	410MB	073	0	0	008 329

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CGS-B	16	01	67	15	30	47	10.661N	85.920W	33	470MB	078	0		0	N019*	428
CGS-B	19	01	67	02	19	23	12.561N	86.613W	200	450MB	075	0		0	G024	395
CGS-B	29	01	67	20	11	22	11.953N	88.928W	33	450MB	076	0		0	N018	395
CGS-B	30	01	67	09	30	27	12.196N	87.596W	8	410MB	074	0		0	010*	329
CGS-B	06	03	67	23	31	25	12.389N	87.127W	159	410MB	074	0		0	008*	329
CGS-B	08	03	67	15	52	15	13.049N	88.127W	75	390MB	073	0		0	005*	300
CGS-B	08	03	67	23	07	02	15.131N	88.782W	76	420MB	072	0		0	036*	345
CGS-B	22	03	67	09	15	29	12.653N	87.823W	70	440MB	074	0		0	025	379
CGS-B	25	03	67	07	26	37	12.406N	87.876W	76	400MB	074	0		0	035*	312
CGS-B	27	03	67	14	40	13	12.221N	87.712W	54	420MB	074	0		0	019	345
CGS-B	12	04	67	04	56	25	12.217N	88.102W	33	480MB	076	0		0	N025	445
CGS-B	15	04	67	22	10	08	12.743N	88.163W	33	430MB	076	0		0	N036*	362
CGS-B	18	04	67	08	24	17	11.419N	88.415W	33	400MB	076	0		0	N007*	312
CGS-B	18	04	67	08	29	12	11.751N	87.307W	65	460MB	074	0		0	028	412
CGS-B	18	04	67	07	05	08	10.749N	86.777W	53	480MB	077	0		0	041	445
CGS-B	18	04	67	13	05	15	12.765N	87.943W	86	390MB	074	0		0	007*	300
CGS-B	23	04	67	14	44	10	11.525N	86.480W	82	440MB	074	0		0	014	379
CGS-B	30	04	67	03	10	49	12.632N	86.852W	115	420MB	075	0		0	039	345
CGS-B	08	05	67	14	40	08	12.974N	88.073W	33	460MB	073	0	F	0	N030	412
CGS-B	13	05	67	12	48	00	09.247N	82.395W	68	400MB	080	0		0	008*	312
CGS-B	20	05	67	23	42	19	11.653N	86.714W	33	420MB	074	0		0	N012*	345
CGS-B	23	05	67	17	14	50	10.197N	84.022W	119	430MB	078	0		0	008*	362
CGSPDE	23	06	67	13	30	46	12.930N	87.800W	11	420MB	074	0		0	012	345
CGSPDE	25	06	67	22	52	12	10.700N	86.000W	33	400MB	077	0		0	007	312
CGSPDE	30	06	67	11	42	33	11.030N	86.600W	44	450MB	074	0		0	022	395
CGSPDE	04	07	67	06	12	57	10.830N	86.400W	33	410MB	077	0		0	016	329
CGSPDE	04	07	67	13	29	04	11.600N	87.200W	33	420MB	074	0		0	010	345
CGSPDE	04	07	67	07	39	20	11.800N	87.300W	38	400MB	074	0		0	016	312
CGSPDE	14	07	67	18	02	08	13.500N	88.800W	147	460MB	073	0		0	014	412
CGSPDE	11	08	67	12	26	18	11.800N	85.900W	21	470MB	075	0		0	017	428
CGSPDE	27	08	67	13	08	55	12.300N	86.200W	183	520MB	075	0		0	060	511
CGSPDE	02	10	67	15	59	43	11.730N	86.800W	39	470MB	074	0		0	025	428
CGSPDE	03	10	67	19	22	39	10.400N	86.200W	33	450MB	077	0		0	019	395
CGSPDE	03	10	67	18	16	03	10.930N	85.900W	21	580MB	078	0		0	104	611
CGSPDE	04	10	67	00	12	12	15.700N	88.630W	33	440MB	072	0		0	010	379
CGSPDE	04	10	67	06	02	16	10.700N	86.000W	33	530MB	077	0		0	066	528
CGSPDE	08	10	67	14	28	07	11.330N	86.000W	33	420MB	074	0		0	039	345
CGSPDE	15	10	67	08	00	50	11.930N	86.000W	162	620MB	074	0		0	083	677
CGSPDE	06	11	67	18	49	26	13.500N	88.000W	33	430MB	073	0		0	010	362
CGSPDE	13	11	67	16	05	46	10.400N	85.700W	18	460MB	078	0		0	019	412
CGSPDE	06	12	67	02	53	05	12.530N	87.200W	87	530MB	074	0		0	057	528
DEM 369	24	5	68				12.50	86.50	79	5.1					***	5.1
CGSPDE	04	01	68	10	03	56	12.100N	86.300W	5	460MB	075	0		0	028	412
CGSPDE	26	01	68	10	37	56	12.730N	88.800W	60	390MB	076	0		0	007	300
CGSPDE	28	01	68	08	47	20	12.600N	87.900W	75	440MB	074	0		0	022	379
CGSPDE	28	01	68	18	20	49	12.100N	86.900W	152	440MB	075	0		0	015	379
CGSPDE	01	03	68	16	34	44	11.700N	85.500W	190	460MB	075	0		0	033	445
CGSPDE	03	03	68	08	43	24	10.000N	83.100W	16	410MB	078	0		0	010	329
CGSPDE	14	03	68	10	09	19	12.000N	86.800W	25	450MB	075	0		0	013	395
CGSPDE	24	03	68	17	13	20	12.500N	86.500W	79	510MB	075	0		0	043	495
CGSPDE	01	04	68	07	28	28	12.400N	88.500W	33	440MB	076	0		0	013	379
CGSPDE	03	04	68	00	06	00	12.200N	88.300W	33	430MB	076	0		0	011	362
CGSPDE	18	04	68	04	40	38	12.530N	88.600W	54	490MB	076	0		0	019	462
CGSPDE	28	04	68	10	03	31	11.800N	88.800W	39	490MB	076	0		0	039	462
CGSPDE	06	05	68	21	23	11	13.021N	87.734W	56	460MB	072	0		0	D024*	412
CGSPDE	11	06	68	05	52	33	13.941N	88.761W	199	530MB	073	0		0	D066	528
CGSPDE	02	07	68	16	15	48	09.045N	82.934W	33	420MB	080	0		0	N007*	345
CGSPDE	04	07	68	15	15	59	10.464N	84.056W	113	440MB	078	0		0	012	379
CGSPDE	07	07	68	19	49	36	14.678N	88.939W	134	450MB	072	0		0	017*	395
CGSPDE	14	07	68	03	55	24	15.237N	88.843W	14	450MB	072	0	F	0	033	395

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CGSPDE	17	07	68	06	23	11	10.394N	83.369W	19	510MB		078	0		0	0052	495
CGSPDE	20	08	68	00	34	04	13.135N	87.833W	157	430MB		072	0		0	014	362
CGS 74	15	09	68	04	32	04	13.456N	87.243W	164	390MB		072	0		0	009*	300
CGSPDE	19	09	68	00	37	17	12.143N	88.714W	33	440MB		076	0		0	N014*	379
CGS 77	16	10	68	06	08	45	13.893N	88.250W	16	430MB	4	073	0	F	0	039	362
CGS 80	22	10	68	06	42	01	13.20N	88.247W	64	470MB	5	073	0		0	017	428
DEM 398	24	10	68				12.52	86.73	N	C V						***	611
CGS 92	16	11	68	15	14	37	11.082N	86.911W	33	460MB		074	39MS		0	N018	390
CGS 94	19	11	68	00	09	27	11.336N	86.714W	33	460MB		074	41MS		0	N022	410
CGS 89	21	11	68	07	19	34	11.203N	86.891W	33	450MB		074	0		0	N016	395
CGS 90	28	11	68	13	44	33	12.451N	88.006W	49	490MB		076	0		0	021	462
DEM 393	26	12	68				12.10	86.90	152	4.4						***	4.4
DEM 412	24	9	69				11.65	87.71	100	5.3 CFL						***	5.3
CGS 3	06	01	69	09	24	23	11.440N	87.245W	33	480MB		074	43MS		0	N026	430
CGS 3	06	01	69	09	44	41	11.410N	87.232W	33	430MB		074	0		0	011	362
CGS 4	15	01	69	06	57	22	11.338N	86.813W	72	450MB		074	0		0	010	395
CGS 16	08	02	69	04	56	59	13.624N	88.271W	33	430MB	4	073	0	F	0	N006	362
CGS 15	25	02	69	07	39	00	15.231N	87.466W	15	540MB		072	50MS	F	0	G072	500
CGS 15	25	02	69	02	01	44	15.274N	87.544W	13	430MB		072	0		0	G036	445
CGS 19	09	03	69	07	12	39	13.101N	88.528W	75	440MB		073	0		0	021	379
CGS 20	10	03	69	08	15	08	12.349N	87.455W	62	530MB		074	0		600BRK	059	600
CGS 21	14	03	69	08	47	16	12.916N	86.755W	178	560MB	4	075	0	F	580FAS	D109	580
CGS 23	19	03	69	19	49	22	11.785N	88.087W	23	470MB		076	0		0	021	428
CGS 25	01	04	69	21	19	53	12.677N	88.233W	71	490MB	4	076	0	F	0	038	462
CGS 31	04	04	69	08	43	06	13.534N	88.981W	105	430MB		073	0		0	008*	362
CGS 26	08	04	69	19	41	58	12.670N	88.340W	76	480MB		076	0		0	023	445
CGS 32	24	04	69	22	29	46	11.539N	87.022W	50	440MB		074	0		0	022	379
CGS 33	03	05	69	03	19	06	12.937N	88.449W	77	450MB	5	073	0	F	0	032	395
CGS 38	13	05	69	18	11	39	11.523N	86.509W	72	460MB		074	0		0	037	412
CGS 38	13	05	69	14	16	52	11.469N	86.355W	79	560MB		074	0	F	570BRK	104	570
CGS 38	13	05	69	14	15	52	11.408N	86.369W	71	480MB		074	0		0	037	445
CGS 38	13	05	69	16	39	27	12.447N	87.830W	33	420MB		074	0		0	N007*	345
CGS 35	13	05	69	14	36	16	10.817N	86.338W	33	450MB		077	0		0	N038*	395
CGS 36	13	05	69	17	38	28	11.739N	86.179W	46	490MB		074	52MS		400BRK	042	520
CGS 38	14	05	69	13	49	03	11.515N	86.154W	62	480MB		074	0		0	046	445
CGS 40	06	06	69	16	16	01	12.467N	88.000W	48	500MB	3	076	45MS	F	0	051	450
CGS 41	23	06	69	20	46	40	12.410N	88.052W	33	470MB		076	0		0	N033	428
CGS 42	24	06	69	00	35	05	11.651N	85.717W	100	530MB		075	0		500PAL	G085	500
CGS 46	11	07	69	05	57	12	10.189N	85.484W	30	470MB		078	0	F	0	025	428
CGS 45	11	07	69	07	51	04	10.342N	85.369W	33	500MB		078	0	F	450BRK	N049	450
CGS 51	17	07	69	13	24	22	12.590N	87.006W	175	440MB		074	0		0	G012	379
CGS 48	26	07	69	07	21	00	12.625N	87.798W	84	480MB		074	0		0	039	445
CGS 55	03	08	69	21	17	16	13.342N	88.342W	52	430MB		073	0		0	010*	362
CGS 54	15	08	69	01	43	11	09.473N	83.863W	9	440MB		078	0		0	022	379
CGS 59	04	09	69	06	25	28	13.216N	88.429W	53	460MB	4	073	0	F	0	020	412
CGS 65	01	10	69	08	41	31	12.084N	88.358W	33	440MB	3	076	0	F	0	N011	379
CGS 8	15	01	70	16	57	47	11.614N	86.929W	33	480MB		074	0		0	N008*	445
CGS 8	15	01	70	16	52	42	11.512N	86.733W	70	510MB	3	074	0	F	575BRK	046	575
CGS 8	15	01	70	19	08	59	11.157N	86.015W	33	460MB		074	0		0	N012*	412
CGS 7	20	01	70	08	27	48	11.432N	86.353W	46	540MB		074	0		0	063	545
CGS 11	29	01	70	23	06	38	11.492N	86.086W	215	480MB		074	0		0	G018*	445
CGS 11	31	01	70	22	23	37	15.727N	88.750W	46	500MB		072	45MS		0	050	450
CGS 12	12	02	70	17	22	11	12.139N	86.616W	44	440MB		075	0		0	013	379
CGS 23	18	03	70	23	17	57	10.984N	86.015W	56	490MB		074	0		0	037	462
CGS 26	20	03	70	21	00	08	10.428N	87.364W	34	440MB		077	43MS		0	013*	430
CGS 22	27	03	70	18	39	18	12.631N	86.823W	182	510MB		075	0		0	031	495
CGS 31	16	04	70	05	04	41	09.602N	84.240W	50	430MB		078	0		0	G014*	362
CGS 34	21	04	70	05	37	08	12.947N	87.880W	79	520MB		074	0		0	045	511
CGS 37	25	05	70	23	05	18	10.738N	86.939W	33	480MB		077	0		0	N014	445
CGS 48	05	07	70	05	42	05	12.561N	87.446W	33	450MB		074	0		0	N031	395

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CGS	54	20	07	70	04	58	05	10.366N	87.400W	33	460MB			077	0		0	NG15*	412
CGS	53	C5	C8	70	13	22	05	09.841N	84.317W	56	460MB			078	0		0	023	412
CGS	54	07	08	70	13	03	14	12.325N	87.791W	59	450MB			074	0		0	016	395
CGS	55	12	08	70	11	07	59	10.367N	87.229W	33	450MB			077	0		0	N039*	395
CGS	55	12	C8	70	10	24	23	12.351N	86.539W	33	560MB			075	55MS		530PAS	N057	550
CGS	55	12	08	70	09	24	11	12.015N	86.542W	33	590MB			075	63MS	F	600PAS	N077	630
CGS	62	02	09	70	17	51	35	10.432N	86.015W	33	430MB			077	0		0	N009*	362
CGS	62	06	09	70	20	44	49	12.783N	88.595W	75	450MB			076	0	F	0	017	395
CGS	71	23	C9	70	23	57	45	12.321N	87.446W	70	450MB			074	0		0	029	395
CGS	67	29	09	70	04	42	46	11.473N	85.479W	192	540MB			075	0		540BRK	0132	540
CGS	68	C6	10	70	15	18	54	13.561N	88.312W	192	460MB			073	0		0	018*	412
NOS	75	03	11	70	08	39	12	11.644N	86.112W	100	460MB			074	0		0	D023	412
NOS	80	25	11	70	05	38	12	11.765N	87.920W	36	480MB			074	0		0	014*	445
DEM	428	3	2	71				12.50	86.70	N	0	V						***	581
DEM	431	3	5	71				12.70	87.00	N	0	V						***	581
NOS	9	11	01	71	17	13	48	11.714N	87.794W	33	480MB			074	0	F	0	N014*	445
NOS	14	19	02	71	16	59	40	13.562N	86.795W	176	520MB		3	073	0	F	0	0042	511
NOS	21	25	02	71	04	15	41	12.159N	87.489W	52	530MB			074	0		0	075	528
NOS	30	26	04	71	18	32	20	11.422N	86.760W	69	470MB			074	0		0	040	428
NOS	31	C1	05	71	14	32	12	13.259N	88.499W	93	540MB		5	073	0	F	0	053	545
NOS	41	05	06	71	14	20	42	09.339N	84.232W	26	540MB		3	TD78	51MS	F	0	082	510
NOS	44	10	06	71	11	20	31	11.101N	86.766W	60	490MB			074	0		0	015*	462
NOS	41	11	06	71	11	51	40	12.647N	86.967W	148	450MB			074	0		0	024*	395
NOS	45	16	06	71	04	18	56	11.722N	88.222W	33	450MB			076	0		0	N012*	395
NOS	45	18	06	71	13	36	01	14.678N	87.567W	7	500MB			072	0		0	022	478
ERL	60	05	08	71	22	58	08	09.641N	84.069W	33	490MB			078	0		0	N019	462
ERL	60	12	08	71	05	59	00	12.877N	87.341W	211	470MB			074	0		0	026	428
ERL	77	24	08	71	08	09	37	11.539N	86.323W	33	510MB			074	42MS		0	N069	420
ERL	66	27	08	71	09	21	57	11.839N	88.884W	33	500MB			076	38MS		0	N041	380
ERL	73	29	08	71	08	26	52	11.547N	86.180W	33	490MB			074	0		0	N034	462
ERL	71	13	C9	71	15	33	27	09.973N	87.361W	33	440MB			077	0		0	N007	379
ERL	77	28	09	71	05	47	16	07.821N	86.267W	33	500MB			077	0		0	N036*	478
ERL	81	14	10	71	06	59	10	10.824N	86.268W	33	470MB			077	40MS		0	N020*	400
ERL	81	08	11	71	04	26	16	12.472N	88.165W	66	490MB			076	0		0	031	462
ERL	85	25	11	71	22	06	25	12.759N	87.458W	62	490MB			074	0		0	024	462
ERL	85	26	11	71	04	06	38	12.148N	87.626W	47	440MB			074	0		0	013	379
DEM	438	1	12	71				12.60	86.90	N	0	V						***	585
ERL	1	03	01	72	04	31	04	12.311N	86.300W	33	410MB			075	0		0	N019*	329
ERL	2	C5	01	72	11	52	26	12.286N	86.236W	33	420MB			075	0		0	N019*	345
ERL	8	16	01	72	23	55	10	11.535N	87.582W	62	460MB			074	0		0	014	412
ERL	9	30	01	72	22	25	C1	11.382N	86.750W	43	450MB			074	38MS		0	017	380
ERL	7	30	01	72	19	13	07	11.261N	86.773W	48	460MB			074	44MS		0	027	440
ERL	5	C4	02	72	01	07	43	11.213N	86.891W	52	480MB			074	0		0	019	445
ERL	10	C6	C2	72	10	05	31	10.592N	86.400W	36	440MB			077	0		0	008*	379
ERL	11	17	02	72	09	19	C6	13.269N	88.691W	80	470MB		5	073	0	F	0	031	428
ERL	15	19	02	72	19	41	33	10.674N	86.685W	35	470MB			077	0		0	N014*	428
ERL	11	25	02	72	03	43	47	10.137N	83.414W	88	460MB			078	0		0	019*	412
ERL	14	04	03	72	22	04	23	12.933N	88.743W	64	470MB		4	076	0	F	0	024	428
ERL	16	C5	03	72	21	47	26	11.971N	87.914W	46	460MB		3	074	0	F	0	020*	412
ERL	32	30	04	72	10	55	19	12.836N	88.668W	77	440MB		3	076	0	F	0	019	379
ERL	40	27	06	72	14	45	32	12.182N	86.586W	104	460MB			075	0		0	014*	412
ERL	45	28	07	72	13	53	47	13.151N	87.753W	209	440MB			072	0		0	016*	379
ERL	51	31	C8	72	02	24	09	13.272N	88.513W	50	540MB			073	48MS		0	068	480
ERL	58	26	09	72	03	20	16	12.231N	87.412W	37	460MB			074	38MS		0	016*	380
ERL	61	C1	10	72	06	00	51	11.015N	86.330W	49	420MB			074	0		0	036*	345
FRL	65	02	11	72	18	24	45	11.711N	87.939W	24	460MB			074	0		0	020*	412
ERL	66	19	11	72	04	35	24	12.773N	89.524W	73	560MB			073	0		0	065	578
ERL	71	11	12	72	12	51	04	11.403N	87.151W	27	440MB			074	0		0	D017*	379
ERL	73	14	12	72	03	55	41	11.659N	86.574W	106	460MB			074	0		0	D019*	412
ERL	77	23	12	72	07	17	36	12.050N	86.378W	5	500MB			075	0		0	G029	478

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ERL	76	23	12	72	06	29	42	12.357N	86.119W	5	560MB		075	62MS		CD620PAS	G099	620
EPL	77	23	12	72	07	19	49	12.000N	86.169W	5	520MB		075	0		0	G049	511
EFL	74	25	12	72	00	26	28	15.215N	88.943W	34	460MB		072	0		0	020	412
DEM	457	13	4	73				10.50	85.50	N	6.7						***	6.7
ERL	12	15	02	73	00	15	53	11.534N	86.473W	33	510MB		074	50MS		0	0053	500
ERL	13	23	02	73	19	36	44	09.865N	83.493W	33	470MB		078	42MS		0	N038	420
ERL	12	26	02	73	00	43	39	09.606N	84.229W	33	470MB		078	40MS	F	0	N031	400
ERL	15	C7	C3	73	13	00	45	12.705N	88.027W	64	460MB		076	0		0	013*	412
ERL	22	09	04	73	03	17	48	12.257N	86.553W	167	470MB		075	0		0	035	428
ERL	36	14	04	73	08	34	C0	10.679N	84.759W	33	570MB		078	65MS		CD650PAS	N117*	650
ERL	36	14	04	73	08	54	29	10.711N	84.763W	33	480MB		078	0		0	N034*	445
ERL	36	14	04	73	09	19	03	10.260N	85.015W	33	430MB		078	0		0	N006*	362
ERL	30	07	05	73	11	54	36	12.344N	87.549W	33	430MB		074	40MS		0	N013	400
ERL	35	28	05	73	06	19	00	11.474N	87.266W	42	460MB		074	40MS		0	014*	400
ERL	42	05	C7	73	08	08	07	11.949N	87.541W	48	430MB		074	0		0	015	362
ERL	40	06	07	73	05	21	49	11.962N	87.588W	51	480MB		074	0		0	023	445
ERL	41	07	07	73	07	07	55	11.942N	87.761W	55	430MB		074	0		0	015	362
GS	52	14	07	73	07	55	08	11.637N	87.291W	46	490MB		074	44MS		0	024*	440
GS	51	27	07	73	08	51	11	12.415N	87.407W	33	450MB		074	0		0	N017*	395
ERL	49	27	07	73	19	42	47	12.813N	86.674W	199	530MB	3	075	0	F	0	C111	528
ERL	47	28	07	73	20	48	24	12.333N	87.084W	79	540MB		074	0	F	0	0087	545
ERL	47	04	08	73	00	44	42	09.818N	84.586W	33	530MB		078	54MS	F	520BRK	N083	540
ERL	47	C4	08	73	11	54	16	12.140N	88.983W	33	440MB		076	0		0	N008*	379
ERL	49	19	08	73	22	17	49	12.651N	88.507W	68	510MB	4	076	0	F	0	D033	495

APPENDIX B

PARTIAL LISTING OF RESPONSE PARAMETERS

(A complete listing can be obtained by writing the John A. Blume Earthquake Engineering Center, Department of Civil Engineering, Stanford University, Stanford, CA 94305).

EL CENTRO 1940 SOUTH   DAMPING = 5% (STATISTICS BASED ON INCREMENTS)

PERIOD (SEC)	NBPK	DURATION (SEC)	SA	RMS	LAMDA	P=PROB(A>A*) A* (P=5%)	A* (P=10%)	ENGY	K1 (P=5%)	K1 (P=10%)	K2
.08	365	30.31	.578	.0795	18.80	.159	.122	.336	2.003	1.540	.0439
.10	361	30.31	.566	.0900	16.40	.183	.140	.615	2.029	1.560	.0476
.12	359	30.30	.638	.1036	14.21	.211	.162	1.086	2.034	1.564	.0511
.14	347	30.30	.704	.1209	12.04	.249	.191	1.771	2.058	1.582	.0561
.16	349	32.16	.543	.1250	11.18	.268	.206	2.439	2.142	1.647	.0573
.18	279	28.94	.731	.1306	10.67	.281	.216	2.783	2.151	1.653	.0554
.20	279	31.63	.648	.1443	9.95	.301	.232	3.887	2.088	1.605	.0598
.22	253	31.78	.686	.1454	9.59	.312	.240	4.503	2.149	1.651	.0575
.24	243	31.68	.860	.1534	8.96	.334	.257	5.616	2.178	1.674	.0587
.26	223	30.68	.905	.1719	7.64	.392	.301	7.701	2.281	1.753	.0579
.28	223	32.01	.759	.1524	8.72	.344	.264	6.834	2.255	1.733	.0594
.30	207	32.07	.708	.1460	9.60	.312	.240	6.721	2.137	1.642	.0591
.32	211	34.69	.702	.1401	10.52	.285	.219	7.300	2.033	1.562	.0581
.34	183	35.33	.649	.1277	11.55	.259	.199	6.644	2.031	1.561	.0519
.36	181	35.56	.658	.1342	10.99	.273	.210	7.860	2.032	1.562	.0537
.38	177	35.59	.677	.1444	10.09	.297	.228	9.684	2.055	1.560	.0550
.40	163	36.02	.615	.1471	9.60	.312	.240	9.237	2.121	1.630	.0611
.42	165	36.98	.600	.1502	9.33	.321	.247	10.634	2.137	1.643	.0617
.44	159	37.04	.730	.1690	8.46	.354	.272	14.374	2.096	1.611	.0611
.46	155	37.08	.864	.1858	7.77	.386	.296	18.706	2.075	1.595	.0605
.48	151	37.16	.796	.1740	8.13	.369	.283	17.553	2.118	1.628	.0600
.50	143	36.54	.855	.1672	8.59	.349	.268	16.716	2.087	1.604	.0598
.52	135	35.80	.880	.1730	8.22	.364	.280	18.512	2.106	1.619	.0590
.54	131	35.86	.907	.1766	8.37	.358	.275	20.283	2.027	1.558	.0588
.56	125	35.12	.913	.1771	8.44	.355	.273	20.890	2.004	1.540	.0588
.58	115	32.42	.893	.1743	8.46	.354	.272	19.482	2.033	1.563	.0603
.60	109	31.88	.858	.1628	9.21	.325	.250	17.606	1.998	1.536	.0591
.65	101	30.58	.737	.1778	7.85	.382	.293	22.215	2.146	1.649	.0607
.70	109	37.18	.621	.1612	9.25	.324	.249	24.215	2.009	1.544	.0573
.75	101	37.22	.583	.1261	11.98	.250	.192	16.146	1.983	1.524	.0560
.80	93	37.24	.549	.1336	11.63	.258	.198	19.306	1.927	1.481	.0550
.85	67	28.64	.598	.1768	7.42	.404	.310	28.855	2.257	1.735	.0536
.90	85	37.30	.538	.1410	11.20	.267	.206	24.743	1.897	1.458	.0553
.95	79	37.36	.541	.1190	13.61	.220	.169	18.926	1.850	1.422	.0534
1.00	71	32.90	.517	.1092	15.03	.199	.153	15.115	1.825	1.403	.0560
1.10	69	37.98	.386	.0986	14.76	.203	.156	15.823	2.058	1.582	.0513
1.20	63	38.12	.331	.0952	14.11	.212	.163	16.138	2.230	1.714	.0510
1.30	65	41.36	.237	.0700	18.23	.164	.126	10.505	2.349	1.806	.0512
1.40	57	41.16	.182	.0595	21.85	.137	.105	8.297	2.305	1.772	.0476
1.50	53	41.38	.190	.0557	24.16	.124	.095	7.750	2.226	1.711	.0477
1.60	53	40.20	.195	.0526	28.47	.105	.081	7.052	1.993	1.532	.0537
1.70	47	40.32	.187	.0558	26.20	.114	.088	8.555	2.048	1.574	.0495
1.80	43	40.68	.179	.0604	21.87	.137	.105	10.668	2.269	1.744	.0476
1.90	41	38.84	.173	.0559	25.84	.116	.089	9.462	2.072	1.593	.0489
2.00	39	40.02	.179	.0538	26.64	.112	.086	9.294	2.090	1.606	.0486
2.20	27	28.12	.189	.0564	24.68	.121	.093	8.676	2.153	1.655	.0479
2.40	27	30.36	.190	.0497	30.75	.097	.075	7.622	1.960	1.506	.0491
2.60	31	40.98	.162	.0493	27.44	.109	.084	10.444	2.213	1.701	.0489
2.80	27	37.70	.140	.0561	22.67	.132	.102	13.744	2.355	1.810	.0485
3.00	27	40.94	.115	.0467	27.76	.108	.083	10.946	2.313	1.778	.0483
3.20	33	51.32	.100	.0334	37.76	.079	.061	7.831	2.379	1.828	.0480
3.40	29	50.82	.084	.0226	57.45	.052	.040	3.914	2.311	1.776	.0436
3.60	33	51.94	.067	.0174	75.76	.040	.030	2.663	2.272	1.747	.0486
3.80	31	51.26	.053	.0147	89.39	.034	.026	2.072	2.280	1.752	.0467
4.00	25	44.74	.046	.0145	90.97	.033	.025	1.884	2.266	1.742	.0448
4.20	23	42.50	.041	.0130	101.46	.030	.023	1.509	2.266	1.742	.0456
4.40	23	49.96	.036	.0104	127.68	.023	.018	1.202	2.254	1.732	.0402
4.60	23	55.32	.032	.0098	133.84	.022	.017	1.206	2.293	1.762	.0385
4.80	27	59.78	.030	.0100	131.33	.023	.018	1.356	2.286	1.757	.0457
5.00	33	65.26	.030	.0097	139.75	.021	.016	1.444	2.217	1.704	.0534

EL CENTRO 1940 WEST   DAMPING = 5% (STATISTICS BASED ON INCREMENTS)

PERIOD (SEC)	NBPK	DURATION (SEC)	SA	RMS	LAMDA	P=PROB(A>A*) A* (P=5%)	A* (P=10%)	ENGY	K1 (P=5%)	K1 (P=10%)	K2
.08	336	32.04	.292	.0587	23.07	.130	.100	.163	2.210	1.699	.0454
.10	348	32.00	.330	.0648	20.85	.144	.110	.293	2.218	1.705	.0498
.12	328	32.00	.329	.0749	18.12	.165	.127	.570	2.209	1.698	.0464
.14	326	32.09	.384	.0851	15.83	.189	.145	.884	2.223	1.709	.0524
.16	338	31.93	.416	.1067	12.53	.239	.184	1.748	2.240	1.721	.0564
.18	306	31.07	.450	.1181	11.18	.268	.206	2.448	2.270	1.745	.0565
.20	284	31.06	.510	.1255	10.74	.279	.214	2.915	2.223	1.709	.0614
.22	246	31.09	.584	.1240	11.10	.270	.207	3.212	2.177	1.673	.0570
.24	242	31.61	.470	.1360	9.72	.308	.237	4.555	2.235	1.718	.0582
.26	230	32.30	.485	.1429	8.98	.333	.256	5.558	2.333	1.793	.0572
.28	216	32.21	.415	.1334	9.77	.307	.236	5.332	2.298	1.766	.0565
.30	206	32.27	.427	.1279	10.03	.299	.230	5.275	2.336	1.795	.0575
.32	190	31.77	.452	.1329	9.59	.312	.240	6.038	2.351	1.807	.0569
.34	184	32.02	.396	.1326	9.74	.308	.237	6.490	2.321	1.784	.0576
.36	174	32.42	.445	.1355	9.91	.302	.232	7.350	2.232	1.715	.0563
.38	166	32.68	.481	.1394	9.48	.316	.243	8.370	2.268	1.743	.0557
.40	152	32.38	.566	.1569	8.17	.367	.282	9.938	2.309	1.775	.0618
.42	150	32.26	.502	.1684	7.49	.400	.307	12.009	2.375	1.825	.0625
.44	142	32.16	.544	.1645	7.79	.384	.295	12.157	2.337	1.796	.0612
.46	142	32.70	.590	.1565	8.47	.354	.272	11.881	2.259	1.737	.0620
.48	136	32.80	.622	.1450	9.29	.323	.248	10.816	2.225	1.710	.0609
.50	134	32.86	.638	.1456	9.58	.313	.240	11.365	2.147	1.650	.0625
.52	134	32.68	.638	.1524	9.53	.314	.242	13.193	2.063	1.586	.0638
.54	112	30.98	.625	.1569	9.36	.320	.246	13.988	2.040	1.568	.0575
.56	110	30.76	.604	.1531	9.48	.316	.243	13.766	2.063	1.586	.0587
.58	108	30.80	.585	.1491	9.61	.312	.240	13.686	2.091	1.607	.0590
.60	102	30.78	.569	.1438	9.62	.311	.239	13.211	2.166	1.665	.0575
.65	108	33.58	.452	.1196	11.40	.263	.202	11.114	2.198	1.689	.0587
.70	96	33.02	.430	.1065	12.65	.237	.182	9.513	2.224	1.710	.0561
.75	86	32.82	.433	.0979	14.29	.210	.161	8.670	2.141	1.646	.0535
.80	78	30.10	.435	.1112	11.94	.251	.193	10.857	2.255	1.733	.0569
.85	78	31.50	.337	.0964	14.10	.212	.163	9.157	2.205	1.695	.0571
.90	70	31.22	.342	.0911	15.06	.199	.153	8.548	2.185	1.679	.0550
.95	68	32.52	.284	.0832	15.21	.197	.151	7.864	2.367	1.819	.0540
1.00	58	30.20	.278	.0791	16.39	.183	.141	7.069	2.312	1.777	.0513
1.10	50	28.90	.270	.0847	15.82	.189	.146	8.575	2.236	1.718	.0506
1.20	50	29.86	.348	.1098	11.74	.255	.196	16.463	2.325	1.787	.0527
1.30	50	31.44	.285	.0940	14.08	.213	.164	14.073	2.263	1.740	.0531
1.40	52	36.68	.214	.0827	15.48	.194	.149	13.830	2.341	1.800	.0504
1.50	54	38.82	.190	.0614	20.88	.143	.110	8.515	2.338	1.797	.0537
1.60	50	39.58	.157	.0561	22.35	.134	.103	7.713	2.389	1.836	.0522
1.70	40	36.14	.145	.0501	25.64	.117	.090	5.957	2.332	1.792	.0487
1.80	34	32.56	.147	.0570	22.10	.136	.104	7.310	2.377	1.827	.0490
1.90	34	33.16	.187	.0670	19.78	.151	.116	11.317	2.260	1.737	.0487
2.00	32	34.26	.218	.0758	18.42	.163	.125	15.260	2.146	1.650	.0482
2.20	34	39.10	.189	.0768	16.29	.184	.141	20.835	2.393	1.840	.0466
2.40	32	36.86	.156	.0519	25.22	.119	.091	9.702	2.288	1.759	.0512
2.60	24	33.06	.147	.0512	26.36	.114	.087	9.255	2.220	1.706	.0459
2.80	22	29.96	.148	.0561	23.32	.128	.099	11.006	2.290	1.760	.0493
3.00	22	36.66	.142	.0485	27.94	.107	.082	10.574	2.209	1.698	.0441
3.20	26	41.60	.133	.0432	30.00	.100	.077	10.575	2.314	1.778	.0469
3.40	26	44.52	.123	.0351	37.03	.081	.062	8.069	2.307	1.773	.0458
3.60	22	43.62	.113	.0266	49.52	.060	.046	5.451	2.117	1.627	.0427
3.80	24	46.50	.103	.0264	50.75	.059	.045	5.112	2.240	1.722	.0471
4.00	20	43.40	.094	.0253	53.60	.056	.043	4.678	2.211	1.700	.0437
4.20	24	50.22	.085	.0248	51.86	.058	.044	5.210	2.333	1.793	.0498
4.40	26	55.68	.078	.0241	54.70	.055	.042	5.957	2.273	1.747	.0491
4.60	24	57.24	.071	.0229	58.91	.051	.039	5.788	2.221	1.707	.0460
4.80	24	58.38	.067	.0250	50.80	.059	.045	7.130	2.363	1.816	.0483
5.00	26	64.74	.066	.0285	43.89	.068	.052	10.911	2.398	1.843	.0483

FERNDALE 1951 S44W DAMPING = 5% (STATISTICS BASED ON INCREMENTS)

PERIOD (SEC)	NBPK	DURATION (SEC)	SA	RMS	LAMDA	P=PROB(A>A*) A* (P=5%)	A* (P=10%)	ENGY	K1 (P=5%)	K1 (P=10%)	K2
.08	125	9.46	.138	.0293	46.39	.065	.050	.015	2.202	1.693	.0473
.10	123	9.59	.165	.0375	37.51	.080	.061	.035	2.132	1.639	.0487
.12	123	9.69	.172	.0412	33.09	.091	.070	.058	2.197	1.689	.0522
.14	115	9.87	.240	.0570	23.84	.126	.097	.133	2.204	1.694	.0550
.16	113	10.03	.239	.0582	23.15	.129	.099	.169	2.223	1.709	.0580
.18	107	9.95	.243	.0752	17.71	.169	.130	.333	2.248	1.728	.0590
.20	87	9.69	.296	.0729	20.30	.148	.113	.317	2.025	1.557	.0582
.22	89	9.64	.191	.0672	19.35	.155	.119	.302	2.306	1.772	.0642
.24	69	9.42	.194	.0622	21.67	.138	.106	.285	2.224	1.709	.0538
.26	71	9.96	.221	.0598	22.69	.132	.101	.307	2.207	1.696	.0559
.28	69	10.17	.236	.0634	22.23	.135	.104	.386	2.126	1.634	.0564
.30	71	10.69	.183	.0601	21.66	.138	.106	.394	2.302	1.770	.0585
.32	65	10.34	.169	.0567	22.53	.133	.102	.368	2.345	1.803	.0582
.34	63	10.67	.145	.0524	24.45	.123	.094	.347	2.339	1.798	.0576
.36	59	10.96	.196	.0606	21.79	.137	.106	.510	2.269	1.744	.0551
.38	57	10.88	.239	.0693	19.16	.156	.120	.709	2.256	1.734	.0558
.40	53	10.60	.241	.0638	21.49	.139	.107	.531	2.185	1.680	.0650
.42	49	9.90	.238	.0676	19.96	.150	.115	.595	2.219	1.705	.0665
.44	51	10.74	.231	.0641	21.23	.141	.108	.637	2.202	1.692	.0637
.46	51	11.10	.201	.0517	26.33	.114	.087	.455	2.202	1.692	.0633
.48	49	11.92	.165	.0442	30.15	.099	.076	.375	2.246	1.727	.0589
.50	51	12.28	.143	.0424	31.57	.095	.073	.365	2.239	1.721	.0628
.52	49	12.68	.143	.0464	29.00	.103	.079	.468	2.226	1.711	.0610
.54	49	12.56	.152	.0501	26.62	.113	.087	.575	2.245	1.725	.0624
.56	45	12.16	.135	.0483	28.63	.105	.080	.543	2.165	1.664	.0607
.58	39	11.02	.136	.0467	29.21	.103	.079	.476	2.195	1.687	.0601
.60	41	12.56	.130	.0417	31.13	.096	.074	.455	2.308	1.774	.0564
.65	43	14.20	.112	.0403	31.64	.095	.073	.533	2.348	1.805	.0554
.70	41	14.64	.125	.0492	25.93	.116	.089	.894	2.349	1.806	.0544
.75	35	12.86	.110	.0436	29.83	.100	.077	.679	2.295	1.764	.0555
.80	35	13.34	.084	.0279	46.06	.065	.050	.321	2.329	1.790	.0545
.85	39	14.92	.062	.0206	65.37	.047	.036	.211	2.299	1.767	.0565
.90	37	14.34	.053	.0172	77.12	.039	.030	.152	2.261	1.738	.0582
.95	41	16.00	.044	.0159	82.51	.036	.028	.150	2.277	1.750	.0628
1.00	45	17.40	.047	.0156	65.31	.035	.027	.165	2.246	1.726	.0667
1.10	41	18.82	.035	.0112	119.02	.025	.019	.105	2.246	1.726	.0593
1.20	39	19.08	.033	.0103	127.39	.024	.018	.101	2.278	1.751	.0590
1.30	31	19.30	.033	.0113	115.73	.026	.020	.132	2.285	1.756	.0509
1.40	31	19.50	.030	.0106	122.21	.025	.019	.126	2.302	1.769	.0547
1.50	25	17.36	.025	.0081	161.77	.019	.014	.074	2.290	1.760	.0495
1.60	17	11.42	.016	.0068	189.70	.016	.012	.039	2.311	1.776	.0523
1.70	25	16.26	.015	.0048	268.55	.011	.009	.029	2.310	1.776	.0575
1.80	27	19.48	.014	.0043	304.21	.010	.008	.031	2.279	1.752	.0529
1.90	19	18.30	.014	.0043	297.25	.010	.008	.031	2.330	1.791	.0409
2.00	15	14.02	.014	.0047	274.93	.011	.008	.029	2.315	1.779	.0457
2.20	19	20.06	.012	.0041	321.48	.009	.007	.034	2.272	1.747	.0456
2.40	23	22.60	.013	.0038	345.30	.009	.007	.035	2.264	1.740	.0551
2.60	15	16.22	.014	.0039	357.16	.008	.006	.030	2.149	1.652	.0523
2.80	13	17.00	.013	.0040	346.29	.009	.007	.038	2.181	1.676	.0424
3.00	19	28.32	.011	.0037	351.80	.009	.007	.053	2.292	1.762	.0441
3.20	23	34.64	.010	.0036	349.19	.009	.007	.070	2.269	1.744	.0483
3.40	25	36.44	.010	.0037	354.48	.008	.006	.075	2.256	1.734	.0541
3.60	23	40.04	.009	.0034	397.69	.008	.006	.070	2.246	1.726	.0477
3.80	23	40.02	.008	.0030	443.44	.007	.005	.057	2.284	1.756	.0507
4.00	21	39.80	.006	.0025	521.94	.006	.004	.043	2.301	1.769	.0487
4.20	21	39.36	.005	.0020	647.73	.005	.004	.031	2.274	1.748	.0498
4.40	19	36.48	.005	.0017	802.19	.004	.003	.021	2.230	1.714	.0483
4.60	15	30.62	.005	.0014	973.35	.003	.002	.014	2.124	1.632	.0463
4.80	17	24.30	.004	.0014	1109.13	.003	.002	.011	1.969	1.513	.0695
5.00	13	24.18	.004	.0013	1182.48	.003	.002	.010	1.982	1.523	.0551

FERNDALE 1951 N46W DAMPING = 5% (STATISTICS BASED ON INCREMENTS)

PERIOD (SEC)	NBPK	DURATION (SEC)	SA	RMS	LAMDA	P=PROB(A>A*) A* (P=5%)	A* (P=10%)	ENGY	K1 (P=5%)	K1 (P=10%)	K2
.08	116	10.31	.126	.0291	46.39	.065	.050	.013	2.216	1.704	.0500
.10	134	10.24	.146	.0361	37.15	.081	.062	.033	2.231	1.715	.0532
.12	128	10.34	.160	.0401	34.63	.087	.066	.054	2.159	1.659	.0544
.14	116	10.67	.163	.0440	30.93	.097	.074	.079	2.202	1.692	.0556
.16	110	10.19	.253	.0639	22.20	.135	.104	.207	2.111	1.623	.0556
.18	96	10.15	.362	.0753	19.03	.157	.121	.335	2.090	1.606	.0528
.20	94	10.49	.273	.0678	21.05	.142	.109	.292	2.100	1.614	.0591
.22	86	10.47	.269	.0661	21.15	.142	.109	.312	2.141	1.646	.0543
.24	74	10.30	.237	.0683	20.39	.147	.113	.367	2.152	1.654	.0542
.26	74	10.33	.207	.0659	21.31	.141	.108	.373	2.134	1.640	.0582
.28	68	10.18	.250	.0779	17.57	.170	.131	.567	2.188	1.682	.0571
.30	64	10.65	.327	.0989	14.57	.206	.158	1.067	2.079	1.598	.0528
.32	66	11.36	.272	.0793	17.90	.167	.129	.802	2.110	1.622	.0531
.34	64	11.64	.220	.0566	24.49	.122	.094	.448	2.162	1.662	.0529
.36	58	11.58	.202	.0534	25.74	.116	.089	.406	2.179	1.675	.0528
.38	48	10.70	.235	.0648	22.05	.136	.104	.587	2.097	1.612	.0495
.40	50	10.90	.289	.0789	18.84	.159	.122	.826	2.015	1.549	.0603
.42	46	10.94	.313	.0879	16.28	.184	.141	1.111	2.092	1.608	.0565
.44	46	10.52	.288	.0886	15.73	.190	.146	1.173	2.151	1.653	.0595
.46	50	11.70	.255	.0752	19.05	.157	.121	1.007	2.091	1.607	.0594
.48	44	11.56	.226	.0630	23.37	.128	.099	.742	2.033	1.563	.0543
.50	46	11.64	.193	.0547	25.80	.116	.089	.600	2.123	1.632	.0573
.52	38	10.38	.164	.0515	26.84	.112	.086	.489	2.165	1.664	.0558
.54	44	12.16	.147	.0446	31.66	.095	.073	.445	2.120	1.629	.0574
.56	44	13.36	.137	.0441	31.65	.095	.073	.490	2.145	1.649	.0549
.58	48	14.10	.141	.0466	29.32	.102	.079	.592	2.192	1.685	.0592
.60	46	14.56	.136	.0480	27.92	.107	.082	.683	2.234	1.717	.0560
.65	48	14.98	.172	.0577	23.53	.127	.098	1.139	2.207	1.696	.0592
.70	46	15.44	.134	.0484	27.49	.109	.084	.897	2.252	1.731	.0589
.75	38	15.44	.130	.0494	26.55	.113	.087	.996	2.286	1.757	.0523
.80	38	15.88	.150	.0571	23.04	.130	.100	1.524	2.277	1.750	.0520
.85	38	15.92	.132	.0449	29.97	.100	.077	1.042	2.227	1.712	.0530
.90	32	15.00	.115	.0377	35.97	.083	.064	.746	2.206	1.696	.0495
.95	30	14.50	.116	.0371	37.75	.079	.061	.722	2.141	1.645	.0516
1.00	32	14.46	.113	.0368	38.11	.079	.060	.747	2.135	1.641	.0581
1.10	30	15.78	.090	.0305	46.05	.065	.050	.642	2.130	1.637	.0528
1.20	22	11.28	.072	.0247	59.16	.051	.039	.340	2.051	1.576	.0568
1.30	22	15.28	.061	.0180	78.98	.038	.029	.266	2.104	1.617	.0455
1.40	26	16.64	.053	.0155	91.46	.033	.025	.246	2.115	1.626	.0496
1.50	18	12.22	.044	.0148	97.28	.031	.024	.188	2.077	1.596	.0475
1.60	22	16.26	.037	.0115	124.61	.024	.018	.160	2.094	1.610	.0461
1.70	24	19.44	.032	.0099	138.03	.022	.017	.142	2.203	1.693	.0474
1.60	22	19.28	.031	.0087	158.09	.019	.015	.117	2.170	1.668	.0465
1.90	16	15.22	.030	.0082	166.74	.018	.014	.090	2.163	1.662	.0433
2.00	12	10.76	.029	.0088	162.02	.018	.014	.082	2.113	1.624	.0451
2.20	18	21.04	.025	.0064	212.70	.014	.011	.086	2.210	1.698	.0414
2.40	18	22.38	.019	.0055	252.68	.012	.009	.070	2.156	1.657	.0447
2.60	8	10.10	.014	.0070	181.70	.016	.013	.056	2.347	1.804	.0474
2.80	20	24.88	.013	.0048	282.12	.011	.008	.062	2.216	1.703	.0580
3.00	22	32.20	.012	.0047	283.88	.011	.008	.090	2.237	1.719	.0491
3.20	22	35.52	.013	.0047	289.52	.010	.008	.109	2.217	1.704	.0450
3.40	24	35.60	.012	.0045	295.69	.010	.008	.111	2.246	1.726	.0508
3.60	22	37.28	.011	.0041	326.47	.009	.007	.100	2.251	1.730	.0470
3.60	20	37.08	.011	.0036	371.12	.008	.006	.080	2.251	1.730	.0464
4.00	18	34.68	.010	.0032	415.75	.007	.006	.066	2.267	1.743	.0438
4.20	18	34.02	.009	.0027	505.24	.006	.005	.053	2.185	1.679	.0437
4.40	14	28.80	.009	.0025	579.96	.005	.004	.042	2.056	1.581	.0404
4.60	12	20.92	.008	.0026	589.51	.005	.004	.036	1.936	1.488	.0486
4.80	14	20.04	.007	.0026	609.48	.005	.004	.035	1.914	1.471	.0615
5.00	16	28.56	.007	.0022	674.41	.004	.003	.036	2.021	1.553	.0530

PASADENA 1952 SOUTH DAMPING = 5% (STATISTICS BASED ON INCREMENTS)

PERIOD (SEC)	NBPK	DURATION (SEC)	SA	RMS	LAMDA	P=PROB(A>A*) A* (P=5%)	A* (P=10%)	ENGY	K1 (P=5%)	K1 (P=10%)	K2
.08	250	30.62	.048	.0106	137.67	.022	.017	.003	2.059	1.583	.0667
.10	294	30.74	.054	.0111	128.20	.023	.018	.005	2.111	1.623	.0664
.12	296	30.97	.053	.0117	118.19	.025	.019	.009	2.159	1.660	.0638
.14	296	30.86	.050	.0127	109.99	.027	.021	.014	2.151	1.654	.0642
.16	246	30.54	.059	.0128	109.88	.027	.021	.017	2.131	1.638	.0598
.18	226	30.58	.063	.0134	106.50	.028	.022	.024	2.092	1.608	.0545
.20	222	30.55	.073	.0149	94.16	.032	.024	.034	2.129	1.636	.0576
.22	232	30.63	.080	.0172	79.85	.038	.029	.054	2.182	1.677	.0610
.24	220	31.39	.094	.0191	74.14	.040	.031	.079	2.114	1.625	.0583
.26	208	31.49	.093	.0198	68.80	.044	.033	.096	2.199	1.690	.0576
.28	202	31.86	.090	.0214	63.19	.047	.036	.126	2.215	1.703	.0577
.30	194	31.83	.092	.0233	61.53	.049	.037	.166	2.088	1.605	.0572
.32	172	31.13	.111	.0253	58.62	.051	.039	.211	2.023	1.555	.0533
.34	166	31.15	.096	.0237	60.65	.049	.038	.200	2.080	1.598	.0547
.36	152	31.73	.101	.0212	67.16	.045	.034	.169	2.107	1.620	.0523
.38	150	31.81	.093	.0209	67.65	.044	.034	.172	2.118	1.628	.0549
.40	146	31.68	.106	.0230	60.65	.049	.038	.196	2.144	1.648	.0631
.42	138	31.72	.104	.0265	53.13	.056	.043	.282	2.128	1.635	.0606
.44	134	32.46	.117	.0264	54.88	.055	.042	.304	2.069	1.590	.0595
.46	126	32.56	.119	.0253	57.60	.052	.040	.293	2.059	1.563	.0581
.48	124	32.96	.113	.0270	54.62	.055	.042	.356	2.033	1.563	.0583
.50	118	32.84	.134	.0317	46.70	.064	.049	.527	2.024	1.556	.0563
.52	122	32.72	.155	.0351	42.48	.071	.054	.685	2.008	1.544	.0594
.54	118	32.58	.170	.0350	44.11	.068	.052	.712	1.941	1.492	.0592
.56	112	32.70	.155	.0333	45.64	.066	.050	.681	1.968	1.513	.0573
.58	112	32.52	.154	.0310	49.41	.061	.047	.612	1.953	1.501	.0593
.60	104	32.30	.156	.0321	47.51	.063	.048	.674	1.962	1.508	.0574
.65	98	32.54	.177	.0406	38.21	.078	.060	1.210	1.932	1.485	.0564
.70	92	31.96	.131	.0372	42.28	.071	.054	1.112	1.906	1.465	.0560
.75	86	32.10	.107	.0289	52.71	.057	.044	.728	1.966	1.511	.0555
.80	84	34.94	.082	.0246	59.23	.051	.039	.612	2.054	1.579	.0533
.85	82	36.14	.090	.0261	54.60	.055	.042	.766	2.103	1.616	.0526
.90	62	36.54	.098	.0292	49.92	.060	.046	1.037	2.055	1.580	.0546
.95	76	36.48	.094	.0246	60.22	.050	.038	.778	2.025	1.556	.0532
1.00	72	35.80	.084	.0231	64.09	.047	.036	.720	2.025	1.557	.0533
1.10	68	36.82	.062	.0207	68.43	.044	.034	.665	2.111	1.623	.0532
1.20	66	39.30	.070	.0218	64.59	.046	.036	.857	2.124	1.633	.0528
1.30	62	38.92	.064	.0200	69.87	.043	.033	.810	2.139	1.644	.0520
1.40	50	35.26	.046	.0150	93.23	.032	.025	.442	2.139	1.644	.0500
1.50	54	39.92	.048	.0162	85.58	.035	.027	.622	2.156	1.657	.0515
1.60	54	41.52	.056	.0170	83.93	.036	.027	.762	2.095	1.610	.0527
1.70	48	41.48	.052	.0156	91.11	.033	.025	.701	2.104	1.617	.0484
1.80	44	35.06	.065	.0181	84.44	.035	.027	.835	1.959	1.506	.0560
1.90	40	38.62	.065	.0179	83.90	.036	.027	.924	1.997	1.535	.0500
2.00	48	44.24	.055	.0165	87.33	.034	.026	.965	2.077	1.597	.0542
2.20	46	48.16	.039	.0129	108.05	.028	.021	.737	2.145	1.649	.0505
2.40	40	47.56	.028	.0104	133.97	.022	.017	.509	2.158	1.658	.0486
2.60	28	33.94	.035	.0124	115.72	.026	.020	.575	2.080	1.599	.0509
2.80	34	45.60	.031	.0108	131.92	.023	.017	.615	2.102	1.615	.0506
3.00	34	47.14	.026	.0085	174.98	.017	.013	.425	2.020	1.553	.0518
3.20	30	39.88	.024	.0070	217.19	.014	.011	.278	1.971	1.515	.0541
3.40	36	50.70	.021	.0060	232.98	.013	.010	.288	2.156	1.657	.0514
3.60	38	55.78	.017	.0050	276.04	.011	.008	.235	2.165	1.664	.0526
3.80	32	55.46	.013	.0037	370.34	.008	.006	.146	2.161	1.661	.0445
4.00	34	54.70	.010	.0028	498.41	.006	.005	.086	2.133	1.640	.0501
4.20	32	57.94	.008	.0024	575.56	.005	.004	.069	2.179	1.675	.0469
4.40	32	59.32	.007	.0021	634.75	.005	.004	.060	2.219	1.706	.0470
4.60	34	58.28	.006	.0019	738.28	.004	.003	.051	2.170	1.668	.0496
4.80	28	54.30	.007	.0018	775.98	.004	.003	.048	2.152	1.654	.0435
5.00	30	60.02	.006	.0018	757.68	.004	.003	.052	2.230	1.714	.0456

PASADENA 1952 WEST   DAMPING = 5%   (STATISTICS BASED ON INCREMENTS)

PERIOD (SEC)	NBPK	DURATION (SEC)	SA	RMS	LAMDA	P=PROB(A>A*) A* (P=5%)	A* (P=10%)	ENGY	K1 (P=5%)	K1 (P=10%)	K2
.08	164	30.26	.056	.0146	99.18	.030	.023	.004	2.064	1.587	.0565
.10	168	30.24	.058	.0149	96.42	.031	.024	.007	2.080	1.599	.0604
.12	212	30.26	.059	.0154	92.57	.032	.025	.011	2.102	1.615	.0641
.14	224	30.23	.075	.0163	86.94	.034	.026	.020	2.110	1.622	.0588
.16	216	30.49	.073	.0169	81.06	.037	.028	.025	2.192	1.665	.0628
.18	232	30.25	.079	.0186	74.15	.040	.031	.042	2.176	1.672	.0612
.20	232	30.19	.089	.0205	67.66	.044	.034	.063	2.156	1.657	.0620
.22	226	31.18	.085	.0213	65.24	.046	.035	.081	2.158	1.659	.0613
.24	218	31.42	.099	.0236	58.32	.051	.039	.117	2.181	1.676	.0594
.26	200	31.27	.110	.0245	56.59	.053	.041	.142	2.163	1.663	.0569
.28	188	31.50	.098	.0250	54.83	.055	.042	.161	2.183	1.678	.0574
.30	186	31.90	.110	.0286	48.16	.062	.048	.245	2.172	1.669	.0561
.32	142	31.56	.138	.0311	45.50	.066	.051	.316	2.116	1.626	.0572
.34	166	31.14	.140	.0337	42.66	.070	.054	.398	2.085	1.603	.0547
.36	164	31.71	.130	.0298	46.70	.064	.049	.336	2.151	1.653	.0563
.38	148	32.01	.111	.0271	50.73	.059	.045	.289	2.179	1.675	.0543
.40	142	31.90	.112	.0270	51.14	.059	.045	.263	2.173	1.670	.0629
.42	132	31.78	.131	.0286	48.38	.062	.048	.321	2.164	1.663	.0594
.44	132	31.64	.138	.0329	41.92	.071	.055	.450	2.175	1.672	.0613
.46	136	31.72	.127	.0378	37.30	.080	.062	.641	2.123	1.632	.0642
.48	128	31.56	.139	.0374	37.57	.080	.061	.661	2.133	1.639	.0624
.50	120	31.16	.122	.0338	41.06	.073	.056	.555	2.159	1.659	.0617
.52	108	30.12	.134	.0346	40.79	.073	.056	.589	2.124	1.632	.0593
.54	108	30.10	.156	.0381	38.12	.079	.060	.756	2.061	1.584	.0606
.56	104	31.52	.156	.0398	37.74	.079	.061	.913	1.995	1.533	.0546
.58	112	32.50	.153	.0392	38.31	.078	.060	.954	1.994	1.532	.0607
.60	110	32.64	.162	.0380	39.92	.075	.058	.929	1.976	1.519	.0614
.65	94	32.58	.215	.0459	34.25	.087	.067	1.500	1.906	1.465	.0558
.70	94	32.80	.199	.0598	26.28	.114	.088	2.892	1.905	1.464	.0570
.75	90	33.76	.183	.0476	31.17	.096	.074	2.054	2.019	1.551	.0559
.80	84	32.46	.168	.0492	30.45	.098	.076	2.246	2.000	1.537	.0579
.85	80	33.40	.171	.0505	31.26	.096	.074	2.625	1.899	1.459	.0561
.90	74	33.12	.199	.0532	28.94	.104	.080	3.063	1.946	1.496	.0550
.95	78	35.28	.185	.0571	25.72	.116	.090	4.067	2.039	1.567	.0564
1.00	74	34.66	.168	.0489	31.21	.096	.074	3.131	1.964	1.509	.0565
1.10	62	34.16	.122	.0375	40.08	.075	.057	2.098	1.991	1.531	.0504
1.20	66	38.92	.090	.0287	50.11	.060	.046	1.507	2.083	1.601	.0519
1.30	64	40.46	.093	.0263	55.21	.054	.042	1.446	2.063	1.586	.0518
1.40	58	39.28	.075	.0222	65.71	.046	.035	1.100	2.055	1.579	.0509
1.50	54	39.08	.072	.0195	75.26	.040	.031	.901	2.042	1.570	.0513
1.60	54	41.30	.079	.0231	63.18	.047	.036	1.421	2.055	1.580	.0518
1.70	50	42.16	.070	.0206	70.49	.042	.033	1.236	2.062	1.585	.0497
1.80	48	41.22	.064	.0181	81.18	.037	.028	.977	2.037	1.566	.0522
1.90	40	36.12	.054	.0168	94.45	.032	.024	.781	1.893	1.455	.0519
2.00	42	40.10	.045	.0152	99.83	.030	.023	.737	1.976	1.519	.0526
2.20	42	45.70	.056	.0206	68.41	.044	.034	1.716	2.124	1.633	.0504
2.40	36	40.44	.057	.0202	72.84	.041	.032	1.582	2.034	1.564	.0536
2.60	32	40.78	.047	.0152	100.00	.030	.023	1.098	1.966	1.511	.0457
2.80	34	40.68	.040	.0111	138.00	.022	.017	.640	1.948	1.497	.0517
3.00	30	38.02	.030	.0087	183.54	.016	.013	.420	1.875	1.441	.0488
3.20	32	46.92	.021	.0074	191.22	.016	.012	.353	2.111	1.622	.0511
3.40	34	46.94	.019	.0066	2[illegible].85	.014	.011	.302	2.064	1.586	.0573
3.60	32	48.62	.018	.0054	272.89	.011	.008	.221	2.036	1.565	.0545
3.80	34	51.98	.014	.0044	328.13	.009	.007	.171	2.057	1.581	.0566
4.00	42	57.36	.013	.0041	354.49	.008	.006	.164	2.076	1.595	.0681
4.20	40	58.92	.013	.0042	334.55	.009	.007	.191	2.122	1.631	.0660
4.40	40	62.72	.013	.0042	332.50	.009	.007	.221	2.136	1.642	.0622
4.60	40	64.44	.012	.0040	351.08	.009	.007	.220	2.148	1.651	.0608
4.80	36	66.12	.011	.0035	399.08	.008	.006	.185	2.168	1.666	.0539
5.00	30	65.24	.010	.0029	469.67	.006	.005	.139	2.190	1.683	.0459