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Volume 1
Software Description

Development and Initial Application of Software for Seismic Exposure Evaluation

Prepared for

National Oceanic and Atmospheric Administration

May, 1982

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PREFACE

The objectives of the work described in this report are to develop mathematical models, algorithms, and software to estimate seismic hazard in any tectonic environment. Seismic hazard is defined as the exposure of a given location to earthquake effects expressed as the level of ground motion parameter for a selected probability of exceedance. It is expected that the results of this study may be initially applied to the evaluation of seismic hazard, in areas selected for possible offshore oil and gas development under the Outer Continental Shelf Environmental Assessment Progam (OCSEAP).

This software documentation consists of two volumes.

Volume I of the SEISMIC EXPOSURE software package documentation is a user manual for the SEISMIC.EXPOSURE computer program. It consists of algorithms, inputs from the semi-Markov simulation program MARKOV, and mathematical techniques used to estimate the seismic exposure at a site. Use of the program is illustrated by the discussion of input parameters and completion of sample problems. Appendices provide details on data manipulation, computer algorithms, and the computer environment systems information required to transfer programs from the UNIVAC computer, on which the software was developed, to another computer system. A description of system hardware and suggestions for program modifications for other program capabilities are also provided.

Volume II discusses the methodology and data inputs used in the initial application of the SEISMIC.EXPOSURE computer software to the Gulf of Alaska study region. Data inputs and assumptions about geologic and seismicity parameters defined by Seismological Research Unit participants are included.

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ACKNOWLEDGMENTS

The Development and Initial Application of Software for this Seismic Exposure Evaluation project was sponsored by the Bureau of Land Management (BLM) through a contract with the National Oceanic and Atmospheric Administration (NOAA). Mr. Rod Combellick was the NOAA Technical Manager for the study. The support, encouragement, and guidance from Mr. Combellick is acknowledged. This study is a part of the Outer Continental Shelf Environmental Assessment Program (OCSEAP). Representatives of several Seismological Research Units have participated in the application of computer software to the Gulf of Alaska study region. These representatives are listed below:

Mr. Rodney Combellick Mr. Joseph Kravitz	National Oceanic and Atmospheric Administration
Dr. Hans Pulpan	University of Alaska, Geophysical Institute
Dr. Klaus Jacob	Lamont-Dougherty Geophysical Institute
Dr. Jim Dorman	University of Texas at Galveston
Dr. David Perkins	USGS, Denver
Dr. John Lahr	USGS, Menlo Park
Dr. Bob Page	USGS, Menlo Park

The above named individuals attended two project workshops to review and discuss the methodology and to provide necessary seismic inputs for the first application of the software

package. The participants also provided valuable comments and discussions on the first draft of the user manual. The project team appreciates the participants' support and interest in the study.

The project team consisted of the following personnel from Woodward-Clyde Consultants:

I. M. Idriss	Project Director
Ashok Patwardhan	Project Manager
George Brogan, Paul Guptil, Edd Clark	Geology
Tom Turcotte, John Hobgood, Barbara Bogaert, Linda Seekins	Seismology
Khosrow Sadigh	Earthquake Engineering
Ezio Alviti, Ram Kulkarni	Probability Analysis

Members of the project team were responsible for the four project tasks of reviewing available models, developing software, conducting user workshops, and providing initial seismic exposure maps and consultation on the implementation of the software package at an SRU site.

The project team was assisted by a group of consultants consisting of:

Professor C. Allin Cornell	Probability Analysis
Mr. Ernie Vosti	Computer Systems

Dr. William Hall	Structural Engineering
Mr. Lloyd Cluff	Geology
Professor H. B. Seed	Earthquake Engineering

The consultants provided valuable advice and guidance throughout the project. The project team sincerely acknowledges their participation.

ABSTRACT

The computer software documented in this user manual provides for a Bayesian statistical treatment of seismicity and tectonics that allows inputs of subjective and historical data on seismicity in order to produce seismic exposure map(s) of an area. The seismic exposure resulting from ground motion at a given location is expressed as the level of that particular ground-motion parameter for a selected probability of exceedance.

The software has the capability to model any type of onshore or offshore seismic environment. Earthquake sources are modeled as planes or lines with varying dips. These sources are subdivided into trapezoids over which earthquakes of a given magnitude, represented as user-defined magnitude-dependent rupture planes, are distributed. The significant distance to a site from a given source is taken as the distance between the closest point on the rupture surface to the site. Attenuation of ground-motion parameters is modeled probabilistically with a user-defined magnitude software that can accommodate calculation of seismic exposure for up to 13 ground-motion parameters (e.g., peak acceleration, peak velocity, displacements, and pseudo-relative spectral values for various periods and damping).

Below a user-defined cut-off magnitude, recurrence times of earthquakes at a source are modeled as Poisson processes, while the distribution of earthquake magnitudes is characterized using a Bernoulli model. Above the user-defined cut-off magnitude, earthquake occurrence in both space and time can be characterized using a semi-Markov model.

The semi-Markov model provides a methodology to consider the time and location dependency of the occurrence of great

earthquakes. Waiting times and magnitudes of large earthquakes are determined on the basis of the historical earthquake record. The model defines a discrete state as a given earthquake magnitude and a discrete time as a process governed by transition probabilities. The waiting time in a state is governed by an integer-valued random variable that depends on the presently occupied state and the state to which the next transition is made. The basic parameters are the holding time distribution, the transition probabilities for successive states, and the initial conditions: the magnitude of the most recent earthquake and the elapsed time since that event.

Seismic exposure for a given level of exceedance over a time period of interest can be generated for a single site or combination of sites. Ground-motion values for a grid of sites can be contoured to obtain seismic exposure maps for given ground-motion parameters of interest.

1.0 INTRODUCTION

The SEISMIC EXPOSURE software is discussed in sufficient detail to inform the user of the overall features of this new software package for seismic exposure analysis. The theoretical background of the models used in these programs is discussed by Mortgat and Shah (1979) and Patwardhan and others (1980).

Seismic exposure analysis consists of a definition of earthquake source characteristics, a definition of attenuation of ground-motion parameters, and an estimation of the probability of exceedance of given levels of ground-motion parameters for a specific period of interest. The SEISMIC EXPOSURE software consists of a main program, called SEISMIC.EXPOSURE, and three other programs. The other programs, MARKOV, CONST.PROB, and PLOT.ISO, manipulate input data or output from the SEISMIC.EXPOSURE program in order to generate seismic exposure maps.

In the discussion of source seismicity models and computer program descriptions, two sample problems are used to illustrate the details of formatting the input data to define the geometry of earthquake sources, earthquake recurrence information, attenuation parameters, earthquake fault-rupture data, and site location(s). A set of appendices describe essential aspects of seismologic and geologic data manipulation and computer program flow.

1.1 Program Capabilities

The main capabilities of the SEISMIC.EXPOSURE software package include the following:

- Complex source geometry, such as dipping-plane sources of irregular shape and line sources, can be accommodated.

- Up to 13 ground-motion parameters (e.g., peak acceleration and pseudo-relative spectral values for various periods and damping coefficients) can be analyzed in one run.

- Multiple sites in a grid and multiple grids in a study area can be included in the same run.

- Temporal dependencies of the occurrence of large earthquakes can be included. This provides estimates of seismic exposure that are a function of real time.

- The seismicity of earthquake sources may be characterized by a Bayesian procedure that combines subjective judgments and data on geology and seismology in a systematic and formal manner

- To facilitate sensitivity analyses, the program output includes information on the contribution of individual earthquake sources, selected magnitude ranges, and "seismic gap" filling earthquakes.

- Computed ground-motion parameter values, presented as contour plots, can be previewed on a CRT before being plotted as hard copy at a user-defined map scale.

1.2 Seismic Hazard Evaluation

Elements of the seismic hazard evaluation process are shown schematically in Figure 1. For the purpose of evaluating seismic hazards, seismic sources in a region can be characterized by defining earthquake source location, geometry, and

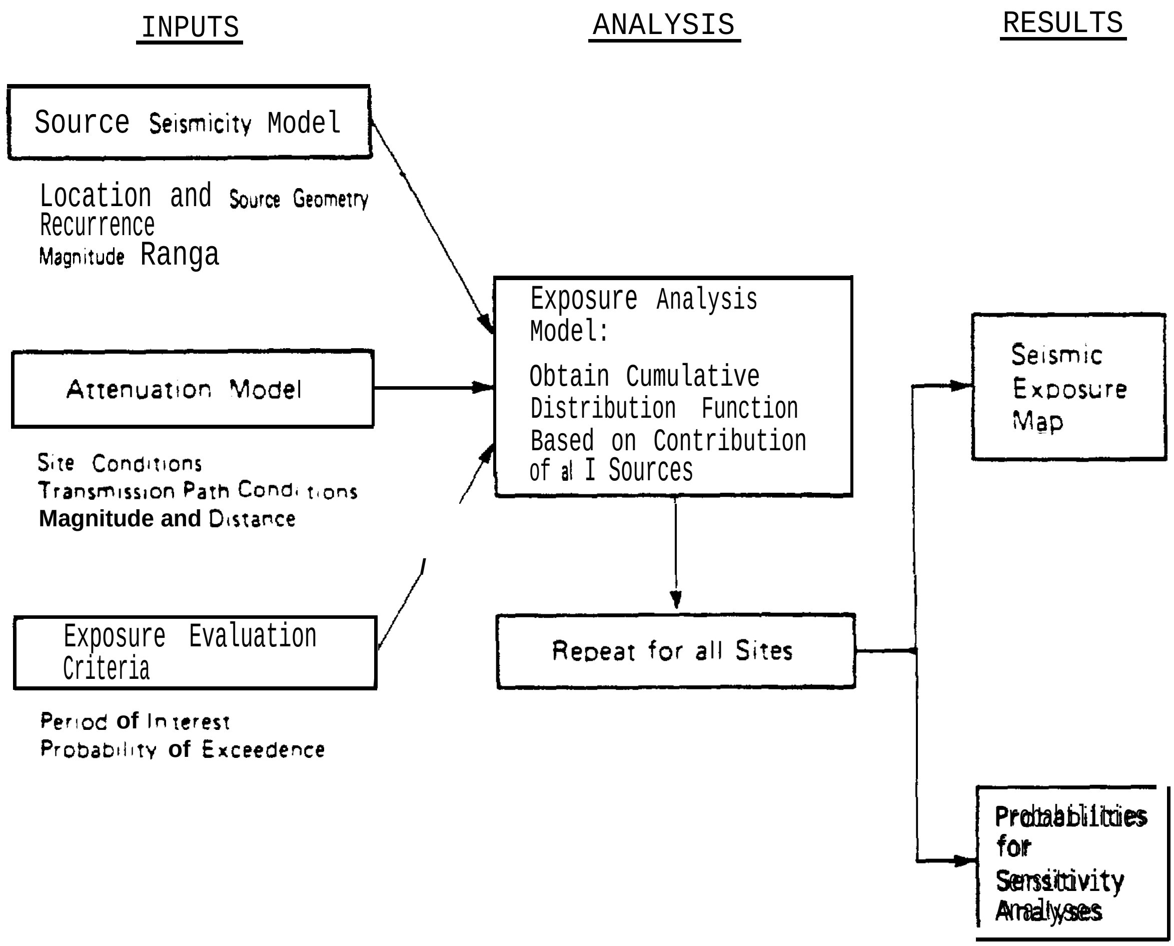


Fig. 1- Schematic Diagram of the Elements of a Seismic Hazard Evaluation - as Implemented in the SEISMIC · EXPOSURE Software Package

recurrence rates. The associated ground motions are attenuated as a function of earthquake size, distance, transmission path, and site conditions. A specific period of interest and probability of exceedance are selected in the hazard analysis model. Contributions from all sources, magnitudes, and distances are expressed in terms of a cumulative distribution function on the ground-motion parameter of interest. This procedure is repeated for all sites and results in data on probabilities of ground-motion parameter occurrence. These values are useful in sensitivity analyses and for seismic exposure mapping.

The elements of the earthquake hazard evaluation scheme are shown in Figure 1. A schematic diagram of the model adopted in the SEISMIC.EXPOSURE software package is shown in Figure 2. The main elements of the program are described in terms of assessing the seismic hazard at sites using a Bayesian statistical probability approach.

1.3 Estimating Earthquake Recurrence

A principal difficulty involved in describing and evaluating the seismic exposure at a site is the selection of a suitable basis on which to estimate earthquake recurrence. Geologic and seismologic considerations for establishing source seismicity and geometries are discussed in Appendix A.

In the program SEISMIC.EXPOSURE, earthquake occurrence is modeled as a Poisson process with a magnitude distribution determined from a Bernoulli probability distribution for earthquakes below a user-defined cut-off magnitude. For earthquakes larger than the user-defined cut-off magnitude, the recurrence description is based on a semi-Markov model (see Figure 2). Using the semi-Markov model to characterize the occurrence of large earthquakes is a primary new feature of this software package.

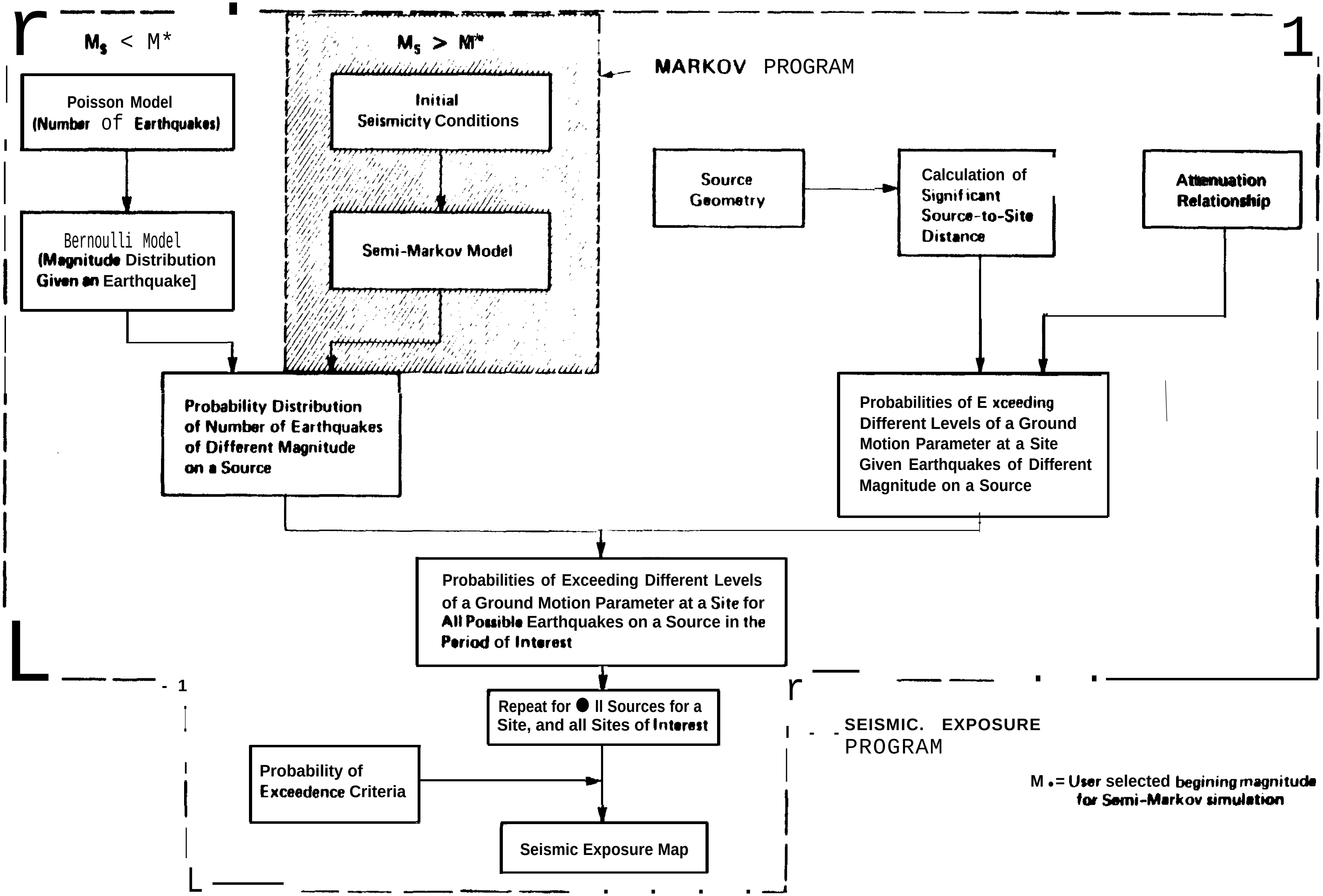


Fig. 2 – Schematic Diagram of the SEISMIC EXPOSURE Software – Package – Components Consist of the SEISMIC. EXPOSURE Program and MARKOV Program for the Semi-Markov Simulation

2.0 SEISMIC.EXPOSURE PROGRAM DESCRIPTION

The program SEISMIC.EXPOSURE has been developed and implemented to compute the seismic exposure for a region that may include a seismic gap. This is accomplished by combining the effects of all earthquake sources within the region in a Bayesian analysis, which provides an estimate of the probability of occurrence of at least one event of a given ground-motion parameter level (e.g., peak acceleration or peak velocity) within a future time period of interest "t." For engineering applications, this time period is typically on the order of 25 to 40 years for engineering applications.

2.1 Source Geometry

In order to describe the source geometry properly, the user is required to input the coordinates (in degrees of latitude and longitude, or in inches, measured directly off a map) of the end points (or nodes) of line sources, and of the vertices (or nodes) of each trapezoid source in order to describe constant depth-area sources or the different bands in dipping-plane sources. Figure 3 shows a schematic of a typical dipping-fault surface and rupture area. Line sources are used to model those faults indicated to have epicenters located at a constant focal depth by historical seismicity data and geologic information. The source can be broken into several segments, depending on its orientation. If there is scatter in the focal depths of historical earthquakes, the source can be modeled as a vertical or near-vertical plane with an appropriate vertical extent.

Recently published relationships between source size (such as rupture length, rupture width, and displacement) and earthquake magnitude (Kanamori and Anderson, 197s) can be used

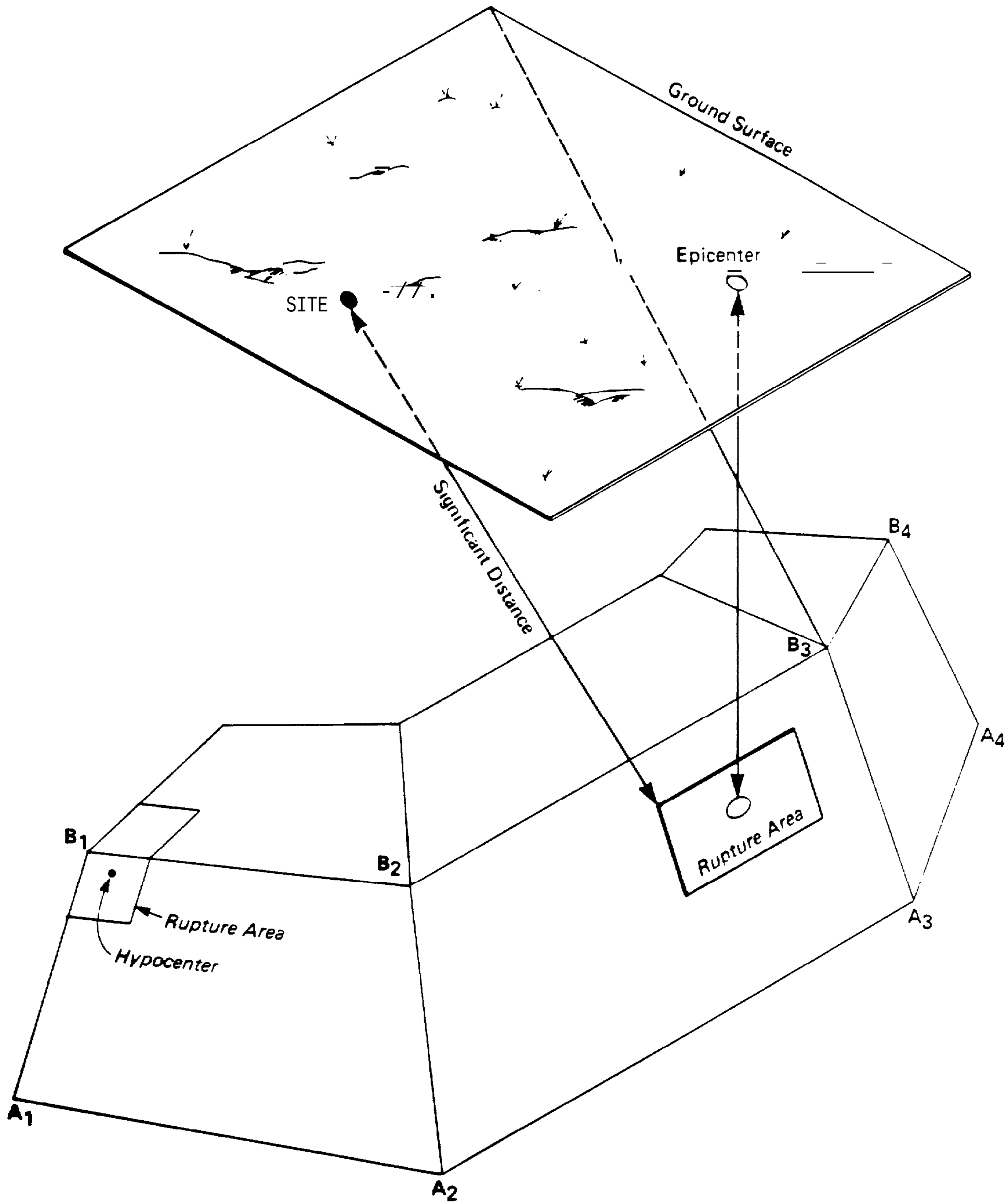
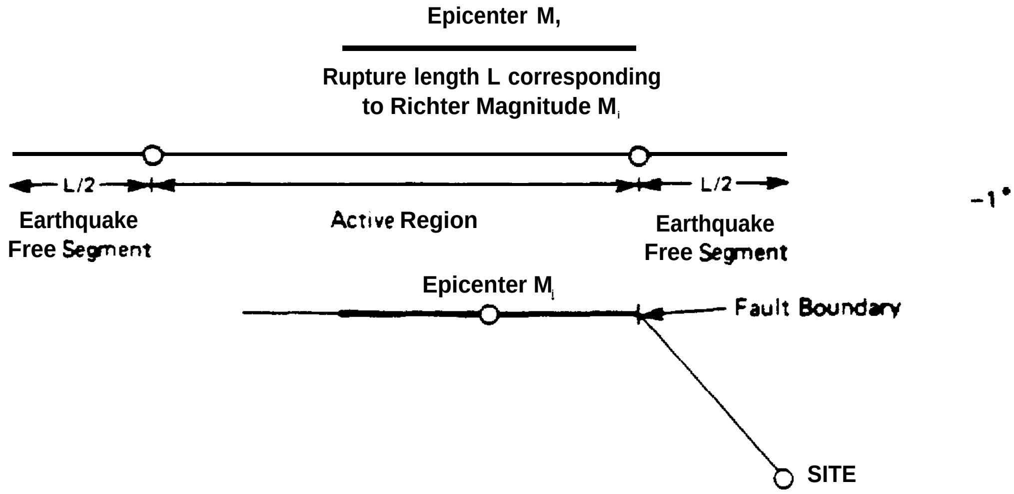


Fig. 3- Schematic Diagram of a Typical Dipping Fault Surface Showing Rupture Areas and Geometry Considerations in Modeling Planar Earthquake Sources

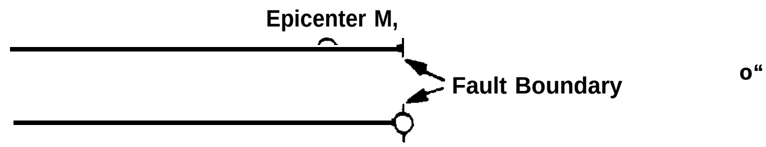
to provide estimates of maximum earthquakes projected to occur on a given fault. The representation of earthquake sources as planar areas permits the use of a magnitude-dependent rupture relationship. This type of relationship more realistically represents the rupture along a fault during an earthquake and the distance between fault-rupture planes and a site (Figure 3). Most of these relationships were developed by using data derived from recent large to great earthquakes occurring around the world, including southern Alaska.

Coordinates for nodes are taken from a base map having one of the three available projections: Lambert Conformal Conic projections 1 and 2 or the Transverse Mercator projection. The type of projection and map-scale information are also part of the input data. The program will automatically transform the nodal coordinates from a specific map projection to kilometers (with the convention that longitude is positive for east and latitude is positive for north), taking into consideration the geographic location of the region (e.g., north or south of the equator, east or west of the Greenwich Meridian).

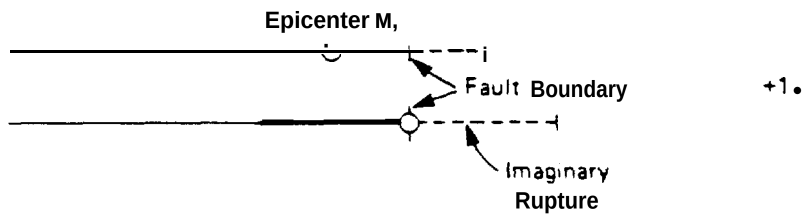
Specific boundary conditions are required to determine the rupture process at the extremities of a source in order to satisfy geometrical and seismologic constraints (fault dimensions and the rupture area per event). These boundary conditions are illustrated in Figure 4. In each case, the distance used is the closest distance from the fault rupture to the site. Boundary condition 1 corresponds to the case in which the earthquake rupture does not propagate beyond the end of the fault, i.e., no surface rupture; the center of energy release corresponds to the center of the rupture area. One-half of the rupture for a given magnitude can extend beyond the edge of the fault. Boundary condition 2 corresponds to a



BOUNDARY CONDITION 1: The edge of the rupture zone coincides with the edge of the source but does not extend beyond it.



BOUNDARY CONDITION 2: The edge of the rupture area coincides with the edge of the source but the center of energy release is not fixed at the centroid of rupture area.



BOUNDARY CONDITION 3: The center of energy release coincides with the centroid of the rupture area but half the rupture may extend beyond the source boundary.

" Program input parameter

Fig. 4- Boundary Condition Options for Establishing the Relation Between the Extent of Fault Rupture at the Boundary (edge or end) of a Source. For Simplicity, a Line Source is Shown.

fault rupture in which the focus is not necessarily at the center of energy release. Rupture ceases at the edge of the source. Boundary condition 3 corresponds to the case in which fault rupture extends beyond the fault boundary, such as when a fault ruptures beyond the active part of the fault. Again, the choice of boundary conditions for a given source dictates how the rupture behaves at the edges of adjacent sources. For multiple dipping sources, the ruptures are assumed to be able to rupture across the edges separating each dipping plane. However, the bounding edges of the source are analyzed according to the selected boundary conditions.

2.2 Source Seismicity

After establishing a geometric model for the occurrence of earthquakes at a source, it is necessary to characterize the distribution of earthquake magnitudes at that source. Most available procedures utilize the Gutenberg and Richter (1954) log-normal relationship (Cornell, 1974; Algermissen and Perkins, 1976; McGuire, 1976). Others have used a Poisson model for earthquake occurrence and Bernoulli's binomial relationship to characterize the earthquake magnitude distribution (Shah and others, 1975; Mortgat and others, 1977).

Recent experience (Patwardhan and others, 1980) suggests that the Bernoulli model for magnitude distribution offers an advantage, both in the treatment of historical earthquake data and in the incorporation of subjective information generated by the Bayesian approach: the uncertainty in both the mean rate of occurrence in the Poisson model and in the probability of success in each trial of the Bernoulli model can be included. The mathematical details of the model can be found in Morgat and Shah (1979).

In this work, the occurrence of earthquakes of magnitude less than a user-specified value M* is assumed to follow a Poisson process having a mean rate of occurrence independent of magnitude. Given that an event has occurred, a distribution over earthquake magnitudes is provided by a Binomial distribution. For earthquakes with $M_s > M^*$, a semi-Markov model is developed. The form of this model is described in Appendix B of this report. The mathematical details of the model can be found in Patwardhan and others (1980). A schematic representation of the earthquake-recurrence model for magnitudes less than M* is shown in Figure 5.

Discretized earthquake-magnitude distributions for each source, time period of coverage, and time period of interest for the analysis are parameters to input for the Poisson and Bernoulli models. For input of the semi-Markov-model data (above the user-selected magnitude threshold), the name of the output file from which the SEISMIC.EXPOSURE program will obtain the magnitudes and probabilities that result from the semi-Markov simulation (obtained through prior execution of the MARKOV program) must be provided.

2.3 Fault Rupture-Length/Magnitude Relationship

The length of the rupture area can be taken from rupture-length and magnitude correlations appropriate for the tectonic environment. It is necessary to input the rupture lengths and down-dip rupture widths for the entire magnitude range of interest in the analysis. Boundary condition parameters are specified in the input data deck or data file to determine the fault rupture process near the extremities of the earthquake source.

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* The program allows the user to change this magnitude value if desired.

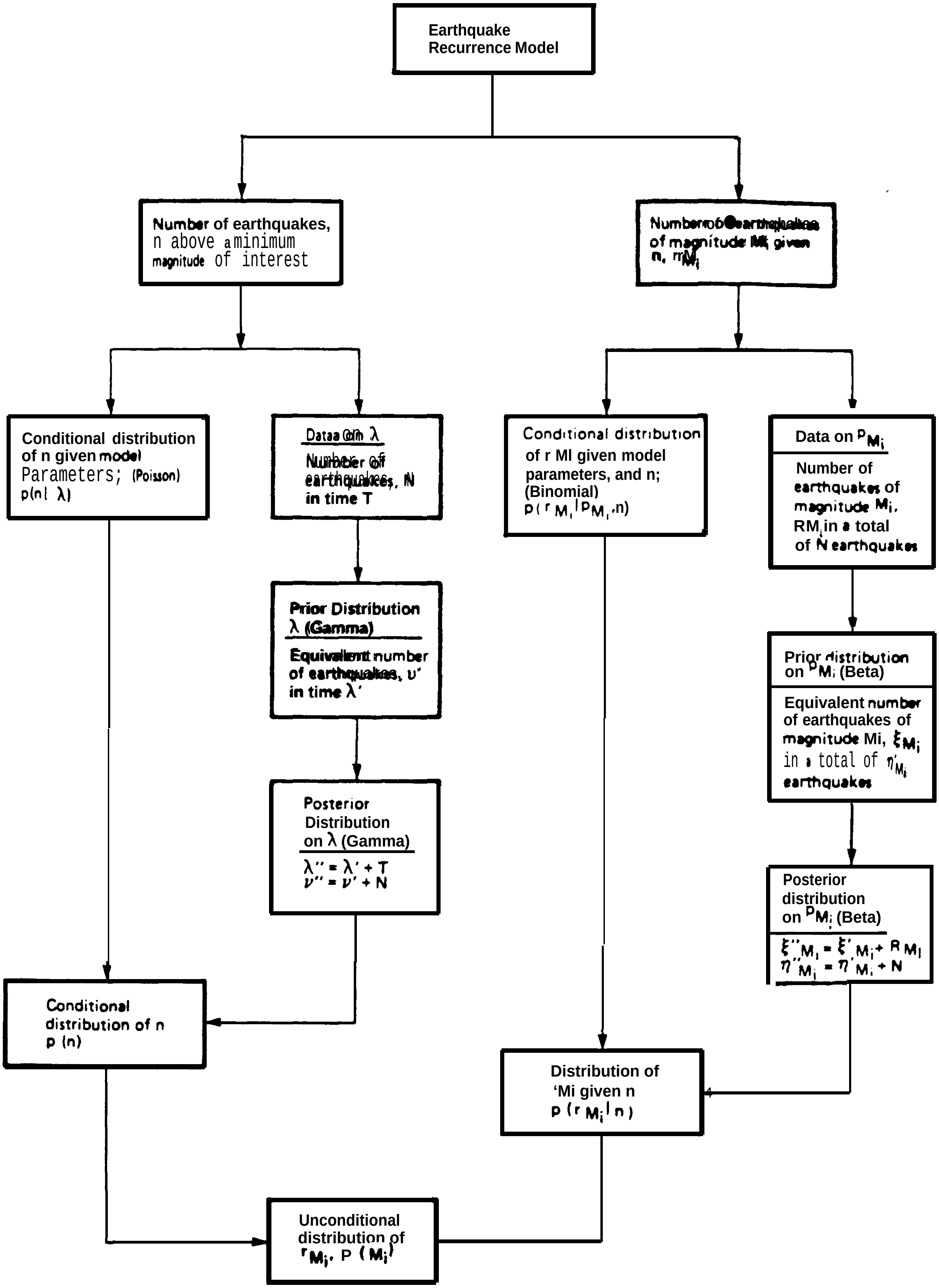


Fig. 5- Schematic Representation of the Earthquake Recurrence Model for Magnitude Less Than M“

If a point-source model (energy released during an earthquake radiated from the hypocenter) is used, instead of the fault-rupture model, it is necessary to set the rupture lengths equal to zero in the input data deck or data file. This procedure will indicate automatically to the program that the point-source model should be used. For small magnitude earthquakes (less than ML 3 or 4), it may be desirable, given source size considerations and distance, to use a point-source model.

2.4 Attenuation Model

Information on the values of attenuation coefficients is included as part of the input data. The number of standard deviations on each side of the mean can be set to indicate to the program whether to consider the attenuation probabilistically or deterministically.

For illustration, a log-normal distribution may be used to represent the uncertainty associated with the relationship. There are attenuation relations (constants) for each ground-motion parameter defined as:

$$a(M,R) = \frac{b_1 e^{b_2 M}}{(R + b_3)^{b_4}}$$

where $b3 = c_1 e^{c_2 M}$

By a suitable choice of the constants in the above equations, attenuation relationships for various ground-motion parameters can be calculated. The uncertainty in the ground-motion regressions can be specified as desired.

Attenuation relations are implemented in the SEISMIC.EXPOSURE program in such a way that the form of the relations can be easily modified or altered completely. At present, up to two attenuation relationships selected on the basis of source depth can be handled. The attenuation relationships can also be restricted to a magnitude range (e.g., only valid between magnitudes 3 and 6).

Because distance is a parameter in the attenuation relationships considered by the program, the area and line sources are divided into small segments in order to consider the variation in distance to the site(s) from different parts of a source. These segment sizes, or increments, are user-defined. While a small step size is desirable in order to approximate continuity (and also to avoid other problems which will be discussed later), the total number of steps is a major influence on the time it takes to run the program. For a run using several large sources, these conflicting factors must be balanced.

The rupture corresponding to the first magnitude starts at a point selected by the program (usually the point on the source closest to the site) . The program then considers a strip of constant depth along the source, one increment wide. It considers epicenters occurring along this strip at distance intervals of one increment. It then adds the contributions from all events whose ruptures include the point currently being considered. It then moves to the next point, and, depending on epicentral proximity to the source boundaries and the corresponding boundary conditions, it recomputes the distance and repeats the process. The point moves along the strip and moves to the other horizontal strips, down-dip and up-dip, until the combined probability for exceeding a given acceleration caused by all the events associated with one source is estimated. The next source then considered, and its contribution, are calculated.

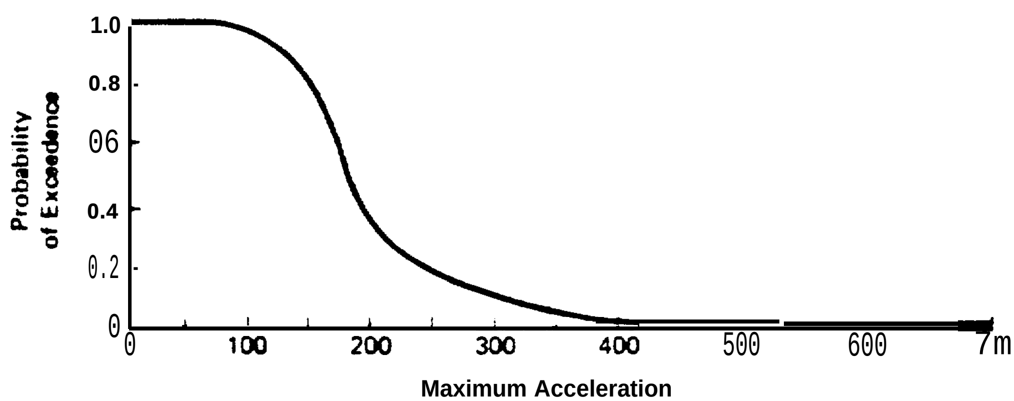


Fig. 6 - A Typical Cumulative Distribution Function for Maximum Acceleration for a Site

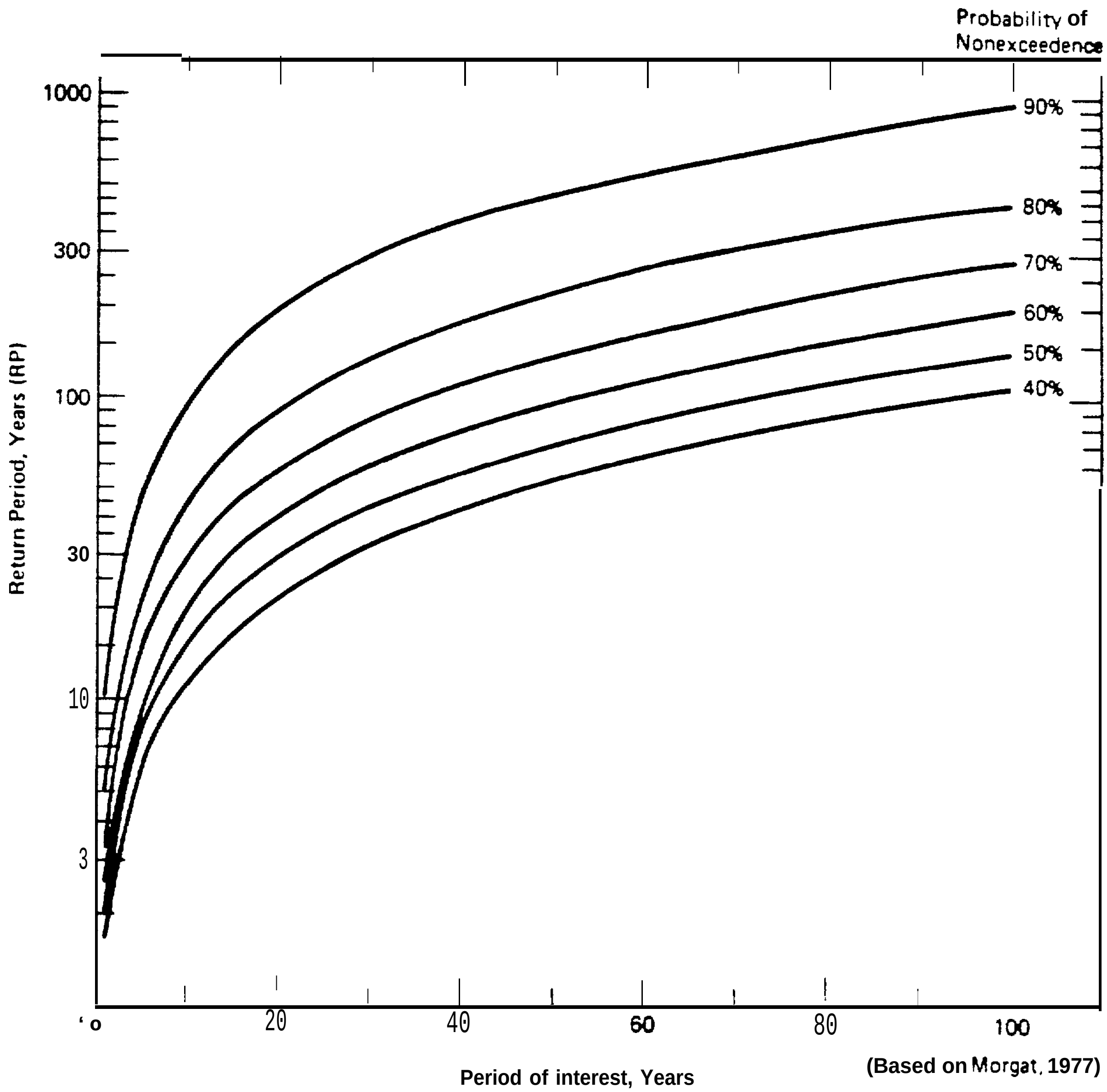


Fig. 7- Relationships Between Return Period, Period of Interest and **Probability** of **Non-Exceedence**

A cumulative distribution function (CDF) or a complementary distribution function (1-CDF) for a ground-motion parameter of interest is developed at a site by choosing a large number of sites at the nodes of a grid covering a given region. The seismic exposure within the region can be described graphically as a contour map of ground-motion parameters.

2.5 Preparation of an Exposure Map

Once a cumulative distribution function is established for each node, a seismic exposure map can be prepared for any desired probability of exceedance or non-exceedance. Before discussing this process, the following definitions are presented :

- Probability of **Non-exceedance:** The probability that a given level of ground motion will not be exceeded within the period of interest.
- Period of Interest: The assumed design life or useful life of a structure or a project.
- Return Period (RF) : The mean (or average) waiting time for an event of interest (assuming a Poisson law of occurrence of earthquakes) .

Figure 7 shows a relationship between return period, period of interest, and probability of non-exceedance using a Poisson distribution for mean rate of occurrence and the Bernoulli binomial law for magnitude distribution.

Following sections of the report address the detailed input data required for executing the program **SEISMIC.EXPOSURE,** which generates probabilities, **average** return periods, and ground-motion values for a site or grid of sites.

3.0 SE ISMIC. EXPOSUR.E PROGRAM ELEMENTS

The SEISMIC.EXPOSURE program consists of a main program, three subprograms, and thirteen subroutines. Figure 8 illustrates the program flow and a summary of the output from each of the major steps in a typical analysis. It is necessary to run the program MARKOV before the program SEISMIC.EXPOSURE is executed if a semi-Markov treatment is desired for great earthquakes or seismic gaps. The MARKOV program data inputs are discussed in Section 4.0.

The array dimensions of SEISMIC.EXPOSURE can accommodate up to 51 earthquake sources, 408 nodes, and 153 elements or trapezoids, 153 bands, and can analyze 13 ground-motion parameters in a single run. The limitation to the number of grids considered per run and to the number of sites or nodal points chosen per grid is determined in the main program on the basis of source geometry. If modifications of array dimensions are desired, a list of subroutines and variables that require changing are included in Appendix D.

3.1 Description of Input Data

A typical region of interest for a seismic exposure analysis is shown in Figure 9. The following descriptions of input data and figures have been modified from work done previously for Woodward-Clyde (1978) and by Guidi (1979). Input data for the software-program package SEISMIC.EXPOSURE can be entered either on cards or in data files. The job control language for using files or cards as data entry elements is discussed in the next section. The following paragraphs describe the data to be entered on 13 cards or equivalent file images.

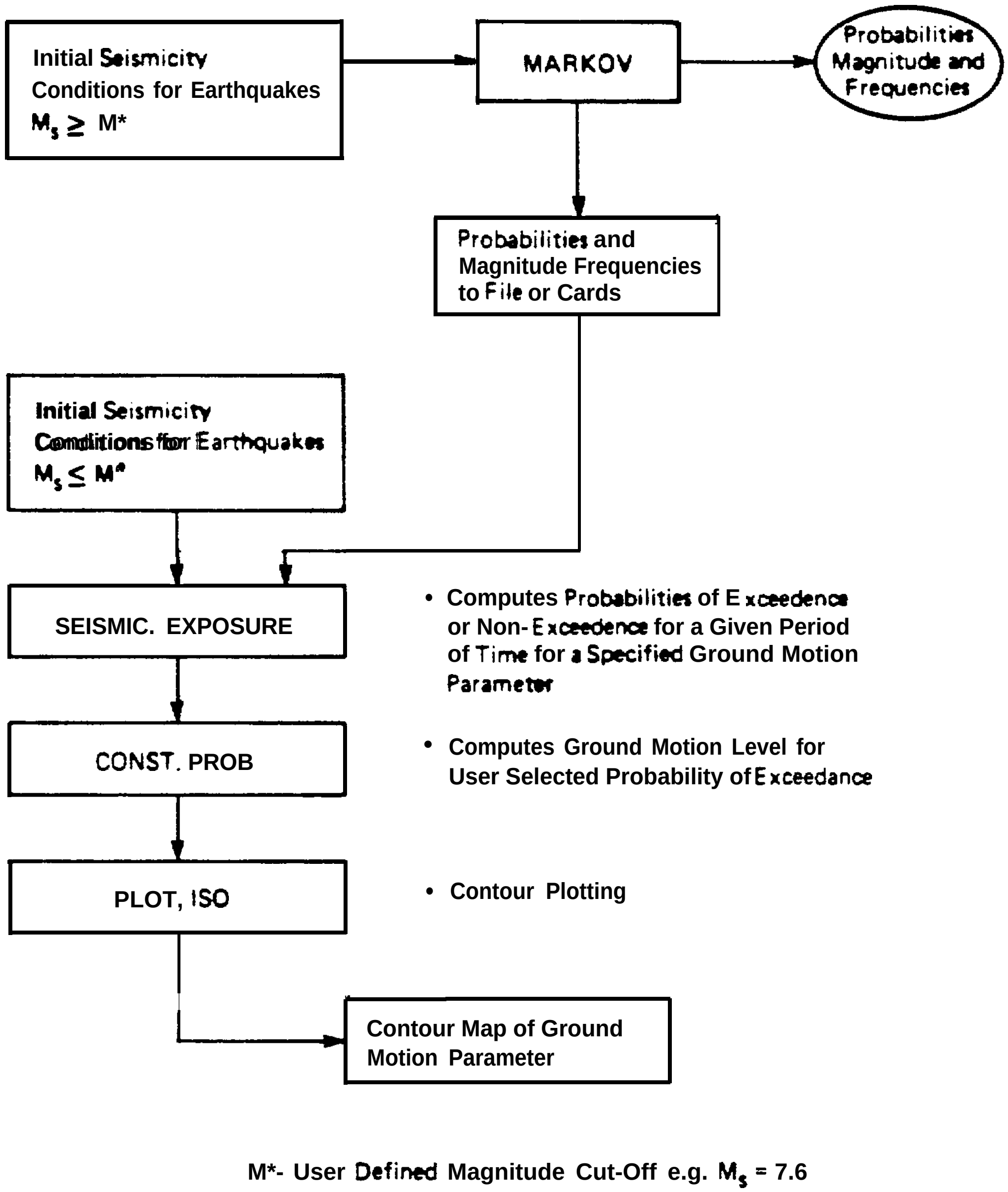


Fig. 8 – Schematic of SEISMIC. EXPOSURE Software Program - The SEISMIC. EXPOSURE Program is the Main Program and can Accept Input from the Semi-Markov Simulation in the MARKOV Program if the Option is Chosen. The Programs CONST. PROB and PLOT. ISO are Sub-Programs of the Main Program SEISMIC. EXPOSURE.

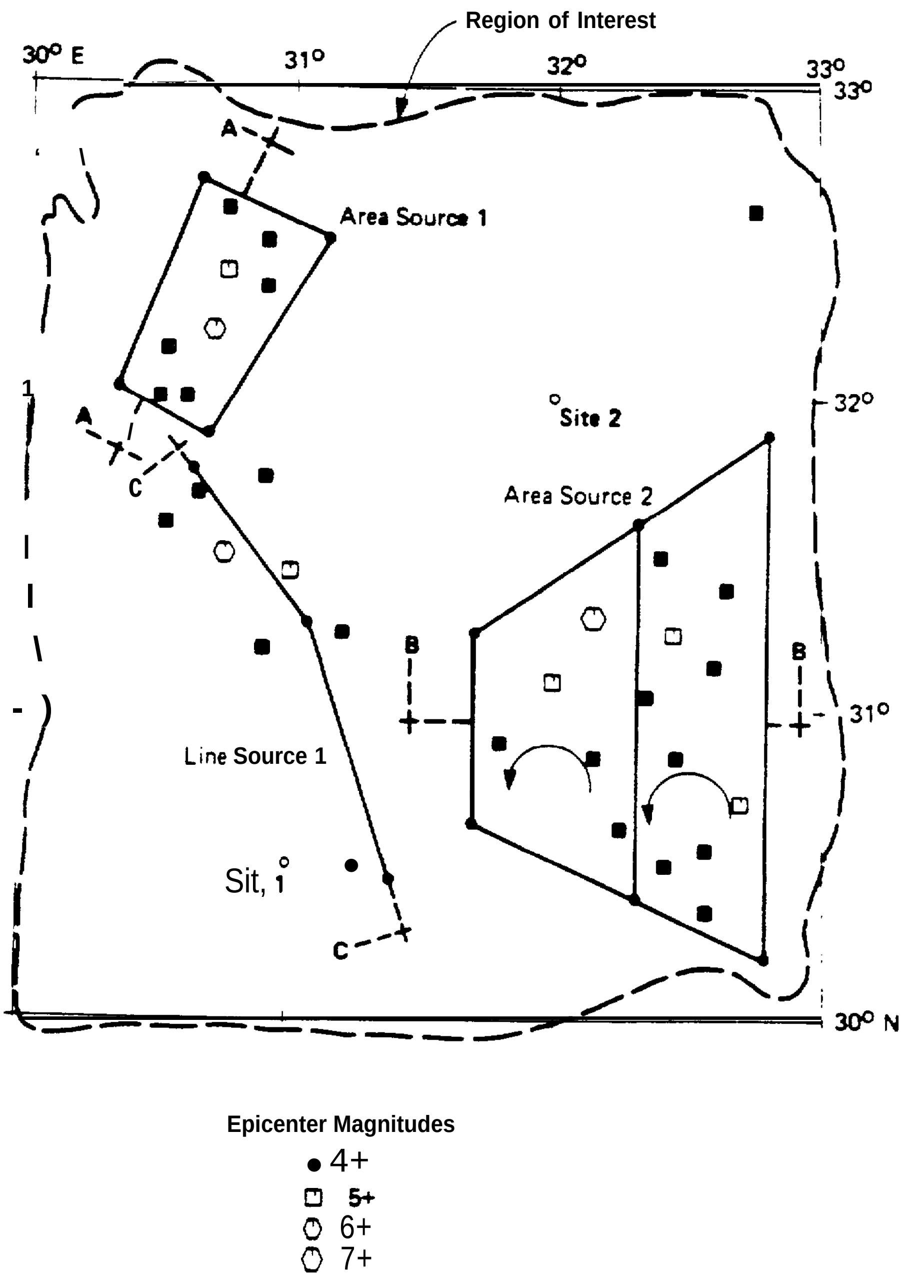


Fig. 9 - Region of Interest with Earthquake Epicenters, Source Geometries, and Cross-Section Lines for Sample Problem 1.

I. Run Identification-- (20A4) --Two cards

Col.	1-80	HED1	Identification Label--Card One
	1-80	HED1	(Continuation) --Card Two

II. Plot Identification--(3I5)--One card

Col.	1-5	I CAL	11 for an n-inch and 30 for a 30-inch Calcomp plotter
	6-10	JFLAG	Map projection: -1 for inches (taken directly from the map), O for Lambert Con ic with one Standard Latitude; 1 for Lambert Conic with two Standard Latitudes; and 2 for Transverse Mercator.

III. Map Projection-- (5F10.0) --One card

Col .	1-10	STLT1	Standard Latitude 1; value is zero for Transverse Mercator
	11-20	STLT2	Standard Latitude 2; input as zero if only one Standard Latitude is used; input zero for Transverse Mercator*
	21-30	STLN	Standard Longitude*
	31-40	SCAL	Not used in this program, but SCAL is used for later generation of seismic exposure maps (see Section 7.2)*
	41-50	DTLB	Distance between grid marks and label default value of 0.5 inches

*These parameters depend on the base maps chosen and are generally available in the legend of the map.

IV. Label Description for Plotting-- (7F10.0)--One card

Col.	1-10	DXCR	X-distance between grid marks, in degrees
	11-20	DYCR	Y-distance between grid marks, in degrees
	21-30	DXLB	X-distance between labels, in degrees
	31-40	DYLB	Y-distance between labels, in degrees
	41-50	DCLV	Increment between contours
	51-60	XMDC	Label every 'XMDC' contour
	61-70	CRCR	Input 1, if marks are desired inside grid, O if not desired

V. Frame Description-- (6F10.0) --One card--must be input

Col.	1-10	XORIG	X-coordinate of origin, in degrees
	11-20	YORIG	Y-coordinate of origin, in degrees

VI. Problem Description-- (16I5)--One card--(A plan view of a typical earthquake source region is shown on Figure 9.)

Col.	1-5	NOAR	Number of area sources
	6-10	NOLN	Number of line sources
	11-15	NOND	Number of nodes
	16-20	NOEL	Number of elements
	21-25	NOGD	Number of grids
	26-30	NOVB	Number of parameters to be studied (e.g., peak ground accelerations, peak velocity)
	31-35	NOAT*	Number of attenuations per parameter--the program allows for two

* See Data Set XIV and Figure 16.

		relationships per parameter; if desired, use 2
36-40	IWPT	FIRST LOGICAL UNIT FOR PRINT,* default is 11
41-45	SADT	Save plot file ? O = NO
46-50	I WDT	FIRST LOGICAL UNIT FOR PLOTFILE
51-55	SAUT	Save output on disk? O = NO
56-60	IWUT	FIRST LOGICAL UNIT FOR DISK OUTPUT*
61-65	MXPR	Number of lines of output printed per site, DEFAULT = 4
66-70	MXSV	Number of values saved on disk per site, DEFAULT = 40
71-75	MXMG	Maximum number of magnitude levels used in this run, DEFAULT = 16 levels, cannot be greater than 18

VII. Source/Magnitude Contribution Table**- (NPPRT+3)I5 One or more cards

Col. 1-5	IPDELT	Ground-motion parameter increment spacing for which tables are desired; e.g., if parameter increment = 20 cm/sec^2 and IPDELT=1, then tables will be printed every 20 cm/sec^2 starting

*Unit 4 cannot be used a write unit - used presently for carriage control and as a scratch file.

**This information is needed for generation of the source/ magnitude contribution table. The dimension of array CPESM dictates how many can be generated. If space is insufficient for all requested tables, parameters will be processed in order given to the array IPPRT above. Remaining parameters will be treated as if they were not specified.

		with lowest value of interest; if IPDELT = 2, then tables will be printed every 40 cm/sec^2; ground-motion parameter increment (DLVBEX) and lowest value of interest (DNVBEX) are read in on card XIII.
6-10	MP LEV	Index of highest value of interest for which a table is generated. This index should be set according to (MPLEV-1)●DLVBEX = Maximum ground-motion value for which a table is generated, where DLVBEX is the ground-motion parameter increment set in card XIII. When the index MPLEV is reached, tables are no longer generated. Since only one value of MPLEV is given for all the ground-motion parameters, MPLEV should be chosen so that the highest value of interest for each parameter is included in the tables.
11-15	NPPRT	Number of parameters for which to generate tables (O = No tables are generated)
16-20	IPPRT(1)	First parameter by input sequence number
21-25	IPPRT(2)	Second parameter by input sequence number
.	.	.
.	.	.
. . .	IPPRT(NPPRT)	Last parameter by input sequence number

VIII. Time Period and Magnitude-- (3F10.0)--One card

Col.	1-10	TMBACK	Time period of interest, i.e., 10, 20, 50, 100 yrs
	11-20	DLMG	Magnitude increment, i.e., 0.25
	21-30	STMG	Smallest magnitude of interest, e.g., $M_S = 5.00$

IX. Nodal Coordinates-- (NOND cards; see Data Set VI)--(I5,3F10.C))

Col.	1-5	I XWC	Node index, e.g., 1, 2, 3
	6-15	XXIN	X-coordinate of node (longitude) , in degrees
	16-25	YYIN	Y-coordinate of node (latitude), in degrees
	26-35	ZZIN	Depth is in kilometers and is negative (see Figure 10).

X. Description of Elements--(415)-- (NOEL cards, see Data Set VI and Figure 11)

Col.	1-5	IXTP(1)	Index of node I (shallow)
	6-10	IXTP(2)	Index of node J (deep)
	11-15	IXTP (3)	Index of node K (deep)
	16-20	IXTP (4)	Index of node L (shallow)

Note: Elements must be specified in sequence of their reference in area source description.

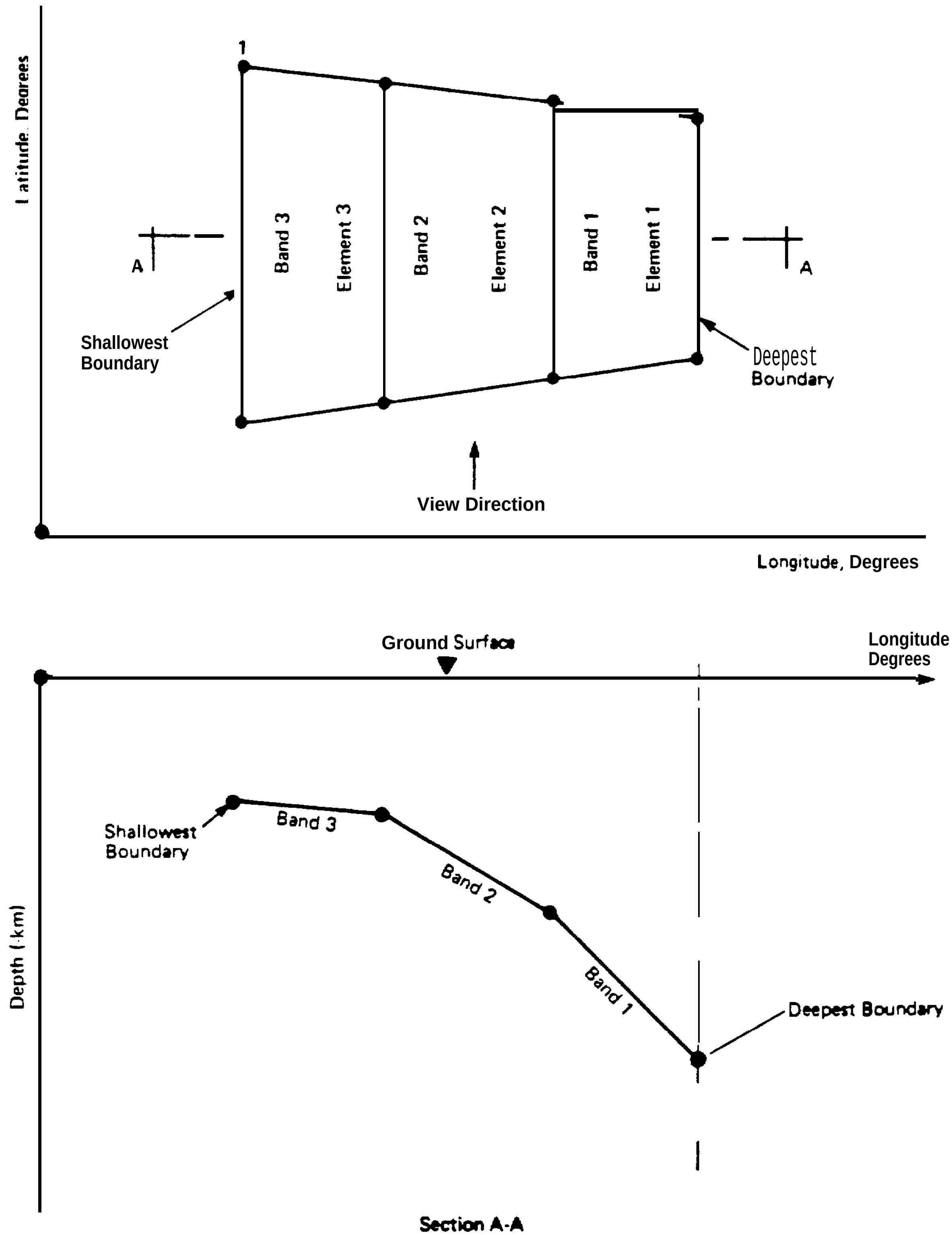


Fig. 10- Node Numbering Convention for Multiple Dip Fault Planes

XI. Area Source Properties--(At least five cards per source)

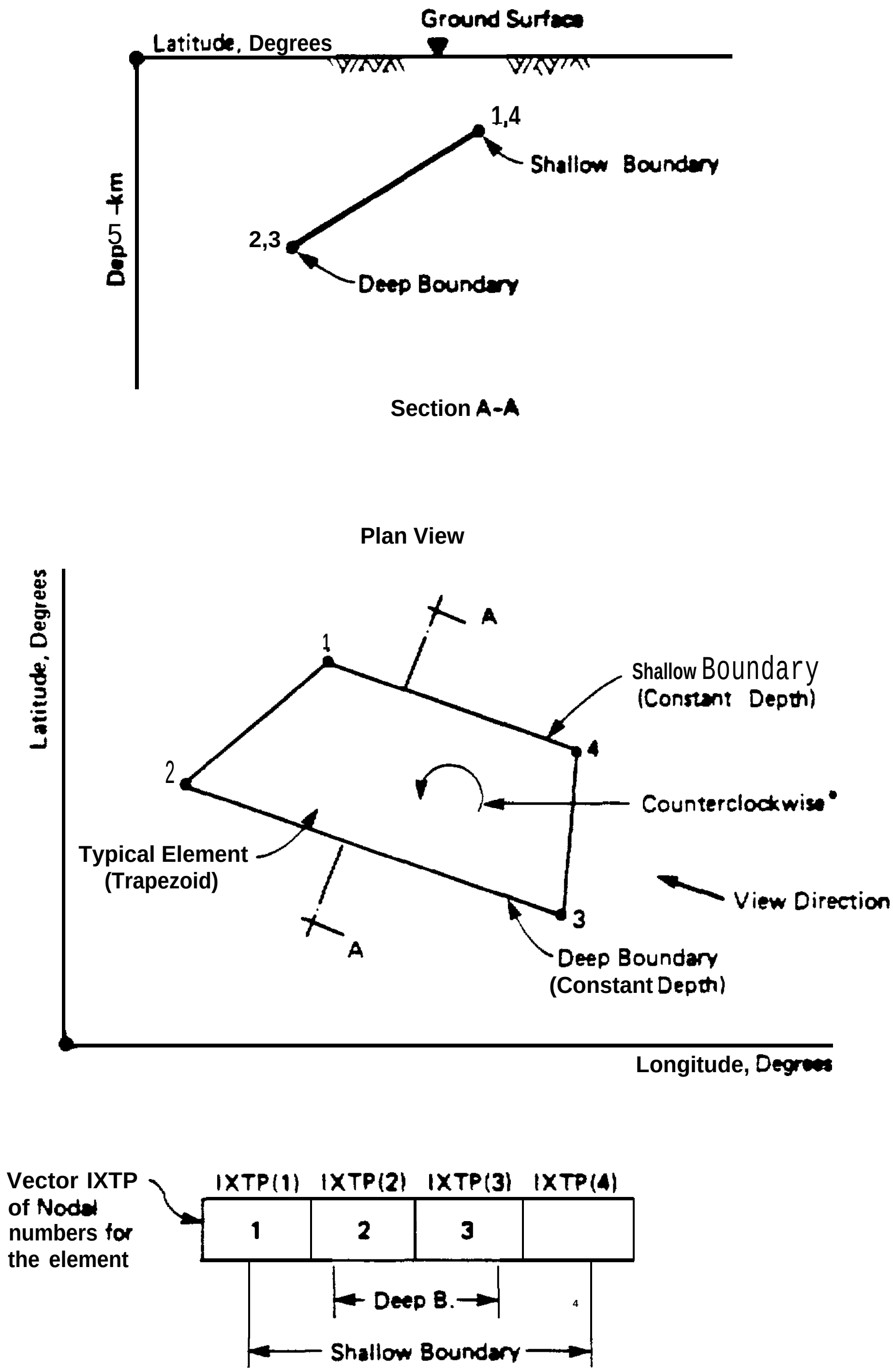
Card 1--(15A4, 3I5)

Col.		
1-60	HED2*	Area source identification*
61-65	NB	Number of different magnitudes (must be 2 or larger)
66-70	NBSM	Number of different semi-Markov magnitudes, 0 if no semi-Markov input
71-75	INDATA	Input unit number for semi-Markov data (default = 5)
76-80	PBCUT	Log_{10} (P # of events) cutoff

Card 2--Geometric Description and Boundary Conditions--(5I5) (see Figures 4, 11, 12)

Col.		
1-5	NOBD	Number of bands
6-10	KXBD (1X,1)	Boundary Condition 1--Deep
11-15	KXBD (1X,2)	Boundary Condition 2--Shallow
16-20	KXBD (1X,3)	Boundary Condition 3--corresponds to side I, J of element
21-25	KXBD (1X,4)	Boundary Condition 4--corresponds to side K, L of element Note: KXBD gets reset to 1 of RUPTUR = 0 (point source)

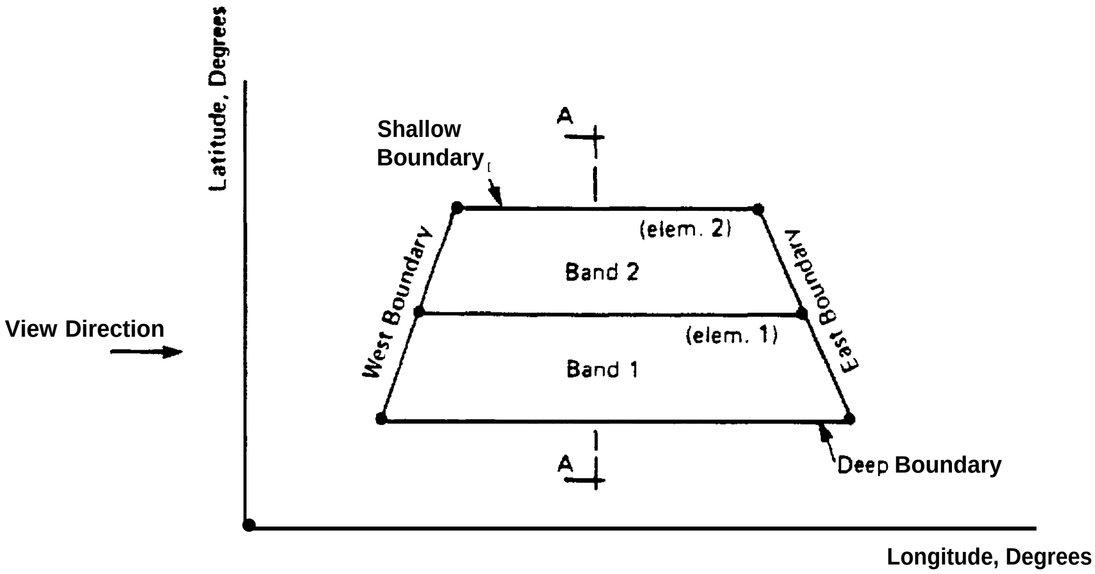
*Must correspond exactly to the MARKOV area source identification label if semi-Markov inputs are being provided in the run.

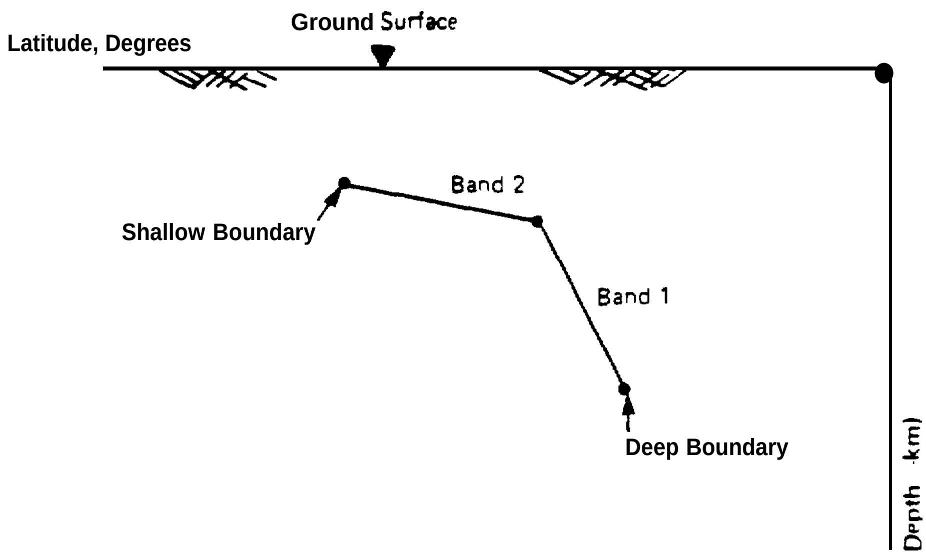


NOTE Because of the program algorithm, area sources at constant depth must be entered with a small slope within the source in order for the program to identify a shallow and deep boundary. If the difference in depth between the opposite boundaries is given small enough, the effect on overall analysis is negligible. Also, as a general rule, all trapezoids must have the parallel sides each at a constant depth.

*When inputting a source from left to right, the element's nodal indices are always read in a counter-clockwise manner. The node indices are input in such a way that the shallow nodes occupy positions 1 and 4 of vector IXTP and deep nodes positions.

Fig. 11 - Conventions For Area Source Geometry





Section A-A

For each boundary (e.g., deep, shallow, west, or cart), the variable KXBD(,) can take one of three possible values:

If KXBD(,) = O, the edge of the rupture area coincides with the edge of the source but the center of energy release is not fixed ● t the centroid of rupture area, see Fig. 4

If KXBD (,) = +1, the center of energy release coincides with the centroid of the rupture area but half the rupture may extend beyond the source boundary, aae Fig. 4

If KXBD (,) = -1, the edge of the rupture zone coincides with the edge of the source but not extend beyond it, sea Fig. 4

Fig. 12 - Boundary Conditions and Dipping Fault Planes

Card 3--Number of Elements in Bands*--(16I5) (See Figure 12)

Col.	1-5	NBELBD(1)	Number of elements in band 1--deep
	6-10	NBELBD(2)	Number of elements in band 2
	.	.	.
	.	.	.
	. . .	NBELBD(NOBD)	Number of elements in band NOBD--shallowest

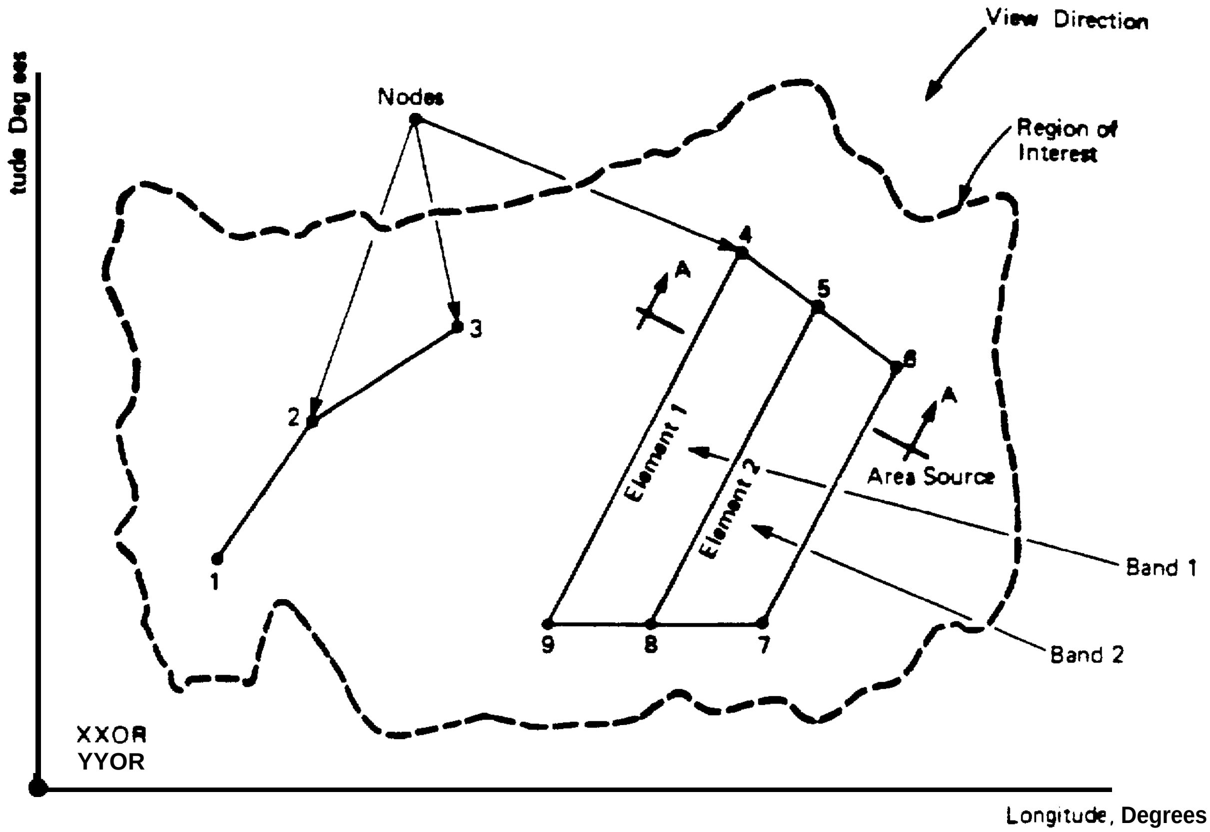
Card 4--Parameters of Poisson and Bernoulli Model**--(8F10.0)

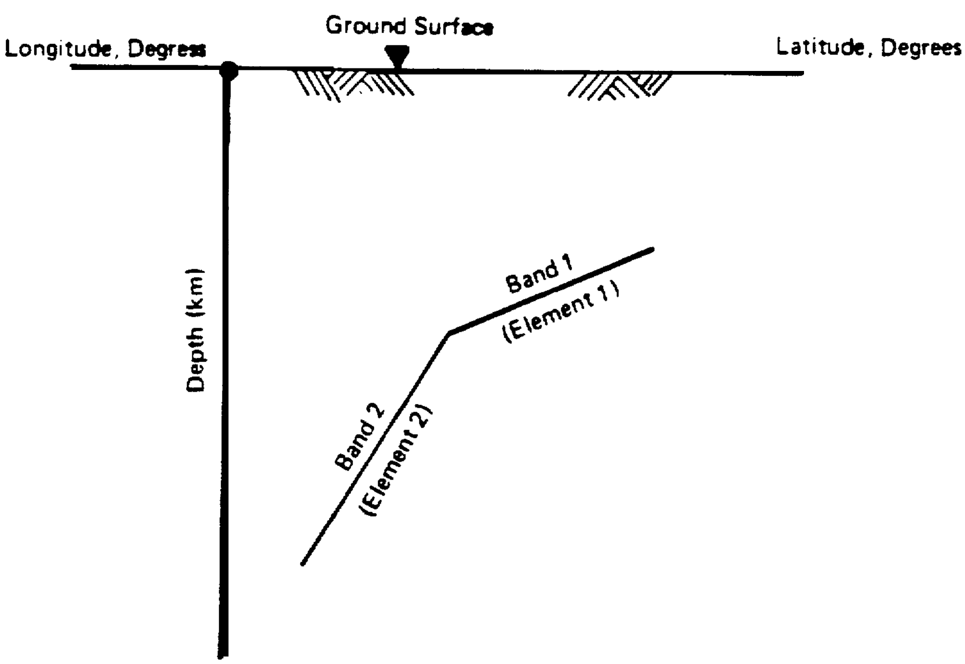
Col.	1-10	TMDA(IXSC)	Time data base
	11-20	XNBDA(IXSC)	Number of events greater than or equal to STMG, the smallest magnitude of interest
	21-30	XNBMG(1,IXSC)	Number of successes for RM = STMG (XNBMG must always be greater than zero. The program takes DLGAMA of XNBMG--an error will result if XNBMG is less than or equal to zero).
	31-40	XNBMG(2,IXSC)	Number of successes for RM = STMG + DLMG
	.	.	.
	. . .	XNBMG(IXSC,NB)	Number of successes for largest RM on this source

Note: IXSC is the index of the iteration control statement for the total number of sources in this run. NB is the number of different magnitudes associated with this source.

*For a given source, the number of elements in each band are read in starting with the deepest band and moving to the shallowest. For example, refer to Figure 12: the area source shown contains two bands (band l--deepest, and band 2--shallowest); each band is formed of only one element (trapezoid). Therefore, for this particular case: NOBD = 2 and hence, NBELB (1) = 1, and NBELBD(2) = 1. The program will take NBELBD elements from the list in card X. The order of the element description must match Card 3.

**Detailed explanation will be deferred until Sections 7.1.1 and 7.1.2.





Sec. A-A (Area Source)

NOTE: For this Particular case:

NOAR = 1
NOLN = 1
NOND = 9
NOEL =2

Fig, 13- Labelling Convention for Line and Area Sources.

XII. Properties of Line Sources--(At least 3 cards per source)

Card 1--(15A4, 315, F5.0)

Col.	1-60	HED2	Line source identification
	61-65	NB	Number of different magnitudes
	66-70	NBSM	See area source description
	71-75	INDATA	See area source description
	75-80	PBCUT	Log 10 (Probability Cutoff)

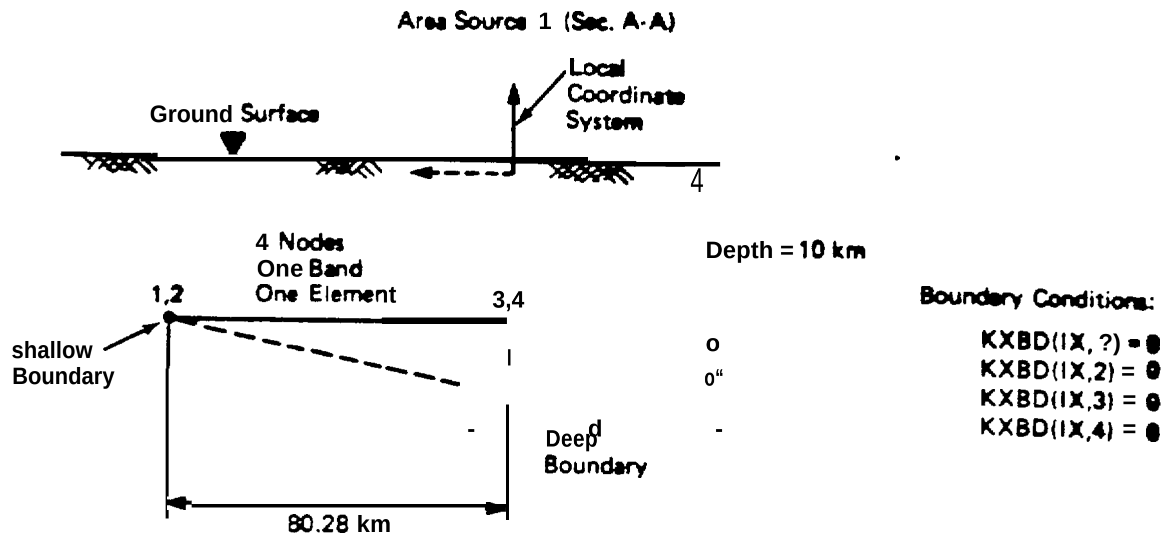
Card 2--Geometric Description and Boundary Conditions--(4I5)
(See Figure 14)

Col.	1-5	NOSG	Number of segments
	6-10	NBELBD( )	Index of first node
	11-15	KXBD(IX,3)	Boundary condition 1--first node
	16-20	KXBD(IX,4)	Boundary condition 2--last node

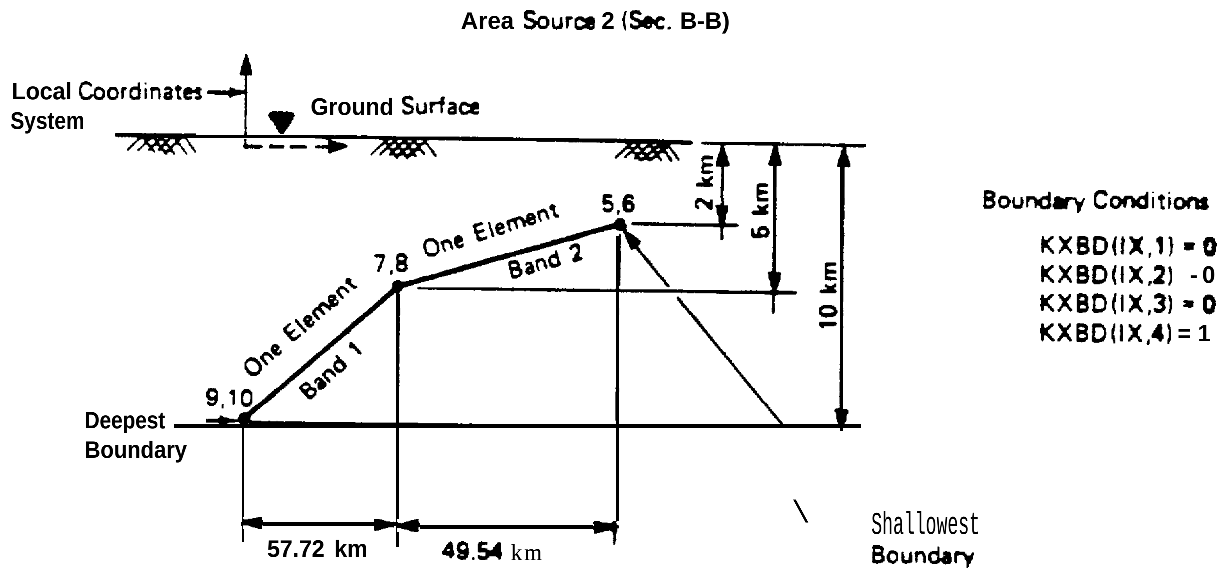
Card 3--Parameters of Poisson and Bernoulli Model*--(8F10.0)

Col.	1-10	TMDA(IXSC)	Time data base
	11-20	XNBDA(IXSC)	Number of events greater than STMG
	21-30	XNBMG(1,IXSC)	Number of successes for RM = STMG
	31-40	XNBMG(2,IXSC)	Number of successes for RM = STMG + DLMG
	.	.	.
	.	.	.
	. . .	XNBMG(NB,IXSC)	Number of successes for largest RM on this source

*Detailed explanation will be deferred until Sections 7.2.1 and 7.2.2.



NOTE: Even though the area source is considered at constant depth, due to the computer algorithm, a difference in height of at least 0.10 km between opposite parallel boundaries should be used.



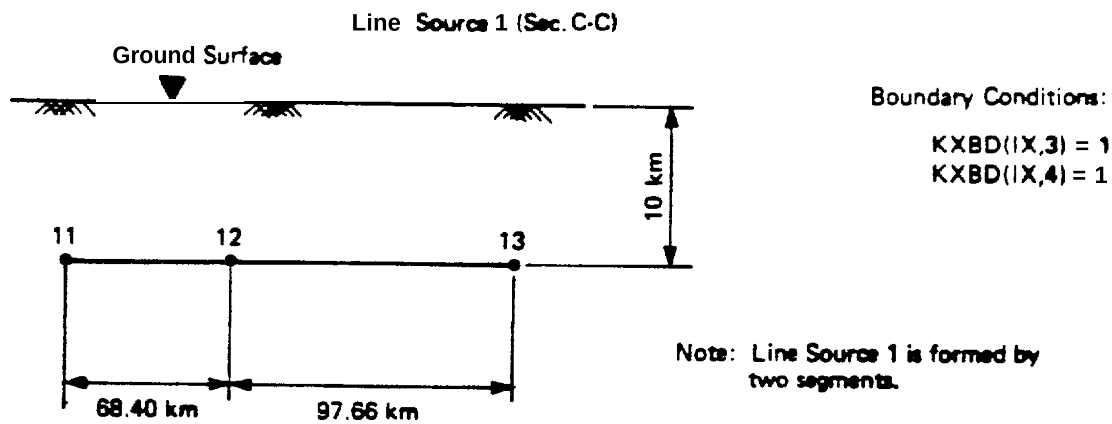


Fig. 14- Source Geometry Crossection

XIII. Attenuation Information--(NOVB sets of 2 or 3 cards; see VI)

Card 1--Identification--(5A4, 3F10.0)

Col. 1-20	HEDVB(IXVB)	Attenuation identification
21-30	DLVBEX(IXVB)	Increment for parameter in this iteration (i.e., if parameter is peak acceleration, then the increment could be taken as, for example, 20 cm/sec^2/see)
31-40	DNVBEX(IXVB)	Smallest value of interest of parameter in this iteration
41-50	UPVBEX(IXVB)	Largest value of interest of parameter in this iteration

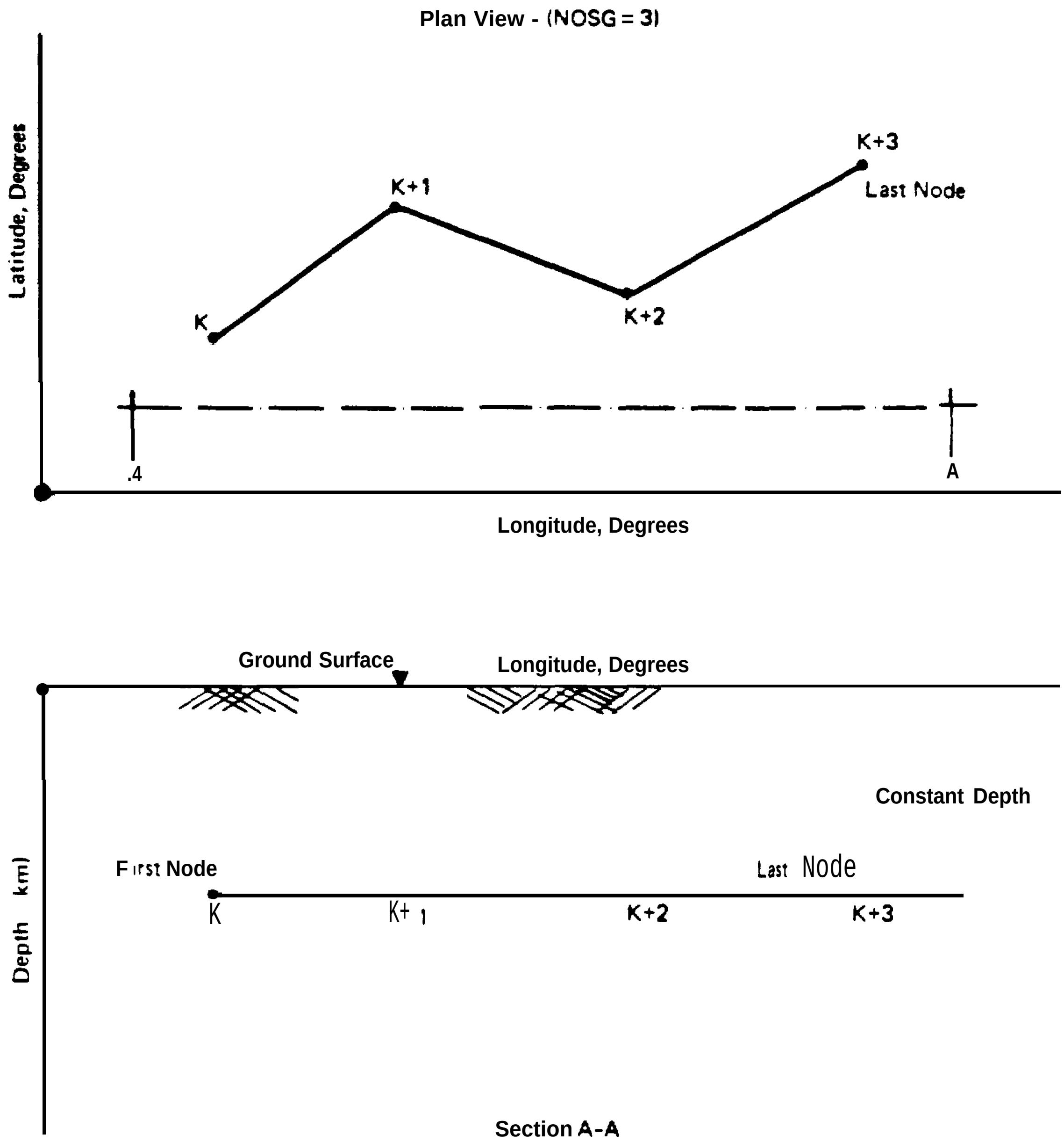
Note: IXVB is the index of the iteration control statement on the number of ground-motion parameters in this run.

Card 2--Attenuation Coefficients for Magnitude Smaller than XMX--(8F10.0) where XMX is the maximum M value for which the coefficients are valid in attenuation relationships of the form:

$$\text{GROUND-MOTION PARAMETER} = \frac{b_1 e^{b_2 M}}{(R + b_3)^{b_4}}$$

Col. 1-10	B1(IXTT)	Coefficient b_1
11-20	B2(IXTT)	Coefficient b_2
21-30	B3(IXTT)*	Coefficient b_3
31-40	B4(IXTT)*	Coefficient b_4

*The user has the option of entering different b_3 and b_4 coefficients because, depending on the desired c_1 and c_2, b_3 can be set equal to $b_3 = c_1 e^{c_2 M}$ (also see XIV).



NOTE: In Contrast to area sources (where nodal indices can be numbered in any arbitrary order), line sources have to be numbered in sequential order, starting with the first node. The boundary conditions KXBD(,) can take one of the three possible values, that is, -1, 0, or 1 (see Fig. 4). Depth of all nodes in the source has to be constant.

Fig. 15 - Convention for Nodes of Line Sources

41-50	SIGLN(IXTT)	Standard deviation of log-normal distribution associated with the attenuation relationship; input in log-scale
51-60	XMX	Max imum magnitude" for which coefficients above are valid--if XMX is entered as zero, coefficient is valid for all magnitudes

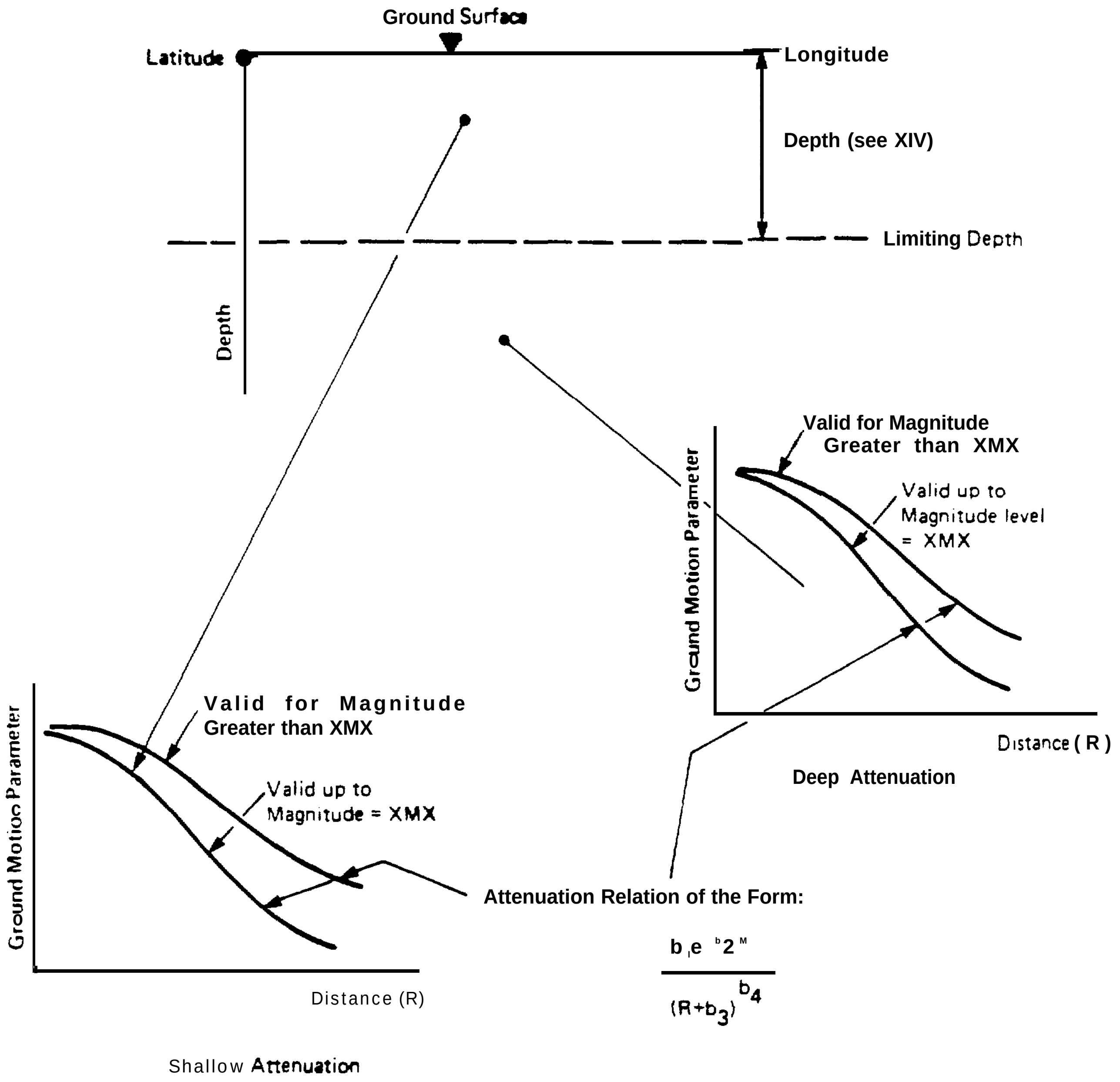
Card 3--Input only if XMX is different from zero--(8F10.0)

Col.	1-10	B11(IXTT)	Coefficient b_1, linear scale
	11-20	B22(IXTT)	Coefficient b_2, linear scale

Card 4--Input Attenuation Coefficients for depths greater than DEPTH (see Card 2 for format, Card XIV for depth). If only one attenuation is desired, Card 4 should be the same as Card 2. It cannot be omitted.

XIV. Information on Distribution Associated with Attenuation Relation--(I10,7F10.0)

Col.	1-10	MXDTIC	Number of steps in distribution; 85 to 101
	11-20	XSIG	Number of standard deviations on each side of the mean--if XSIG = 0, the median curve is used
	21-30	DEPTH	Depth to establish the limit between different attenuation relationships--see Figure 16; this value is irrelevant if the same attenuation is entered twice
	31-40	C1	Coefficient C_1 used to determine C
	41-50	C2	Coefficient C_2 used to determine C



$$\frac{b_1 e^{b_2 M}}{(R+b_3)^{b_4}}$$

The program can handle two attenuation relationships/ground motion parameters (i.e., NOAT = 1 or 2, see VI). The parameter depth in data set XIV establishes the depth limit between the two relationships. The program allows for the specification of a range or validity of the attenuation relationships, e.g., valid between RM = 3.00 and RM = 6.00.
Two attenuation relationships have to be input for each ground motion study. If only one attenuation relationship is to be used, then it should be repeated.

Fig. 16- Example of Attenuation Relations

where: $C^{**} = c_1 e^{c_2 M}$

$$\text{GROUND-MOTION PARAMETER} = \frac{b_1 e^{b_2 M}}{(R + C)^{b_4}}$$

51-60	RPICVR	Vertical integration step in km; if input as zero, Default = 10 km
61-70	RPICHZ	Horizontal integration step in km; if input as zero, Default = 10 km
71-80	EPS	Parameter used for horizontal and parallel checks, use 0.10 km

XV. Rupture Length--(8F10.0)--(One or two cards; if MGMX is ≤ 8, then use only one card; see Figure 17 for a sample relationship)

Col.		
1-10	RUPTUR(1)	Horizontal rupture length corresponding to STMG--smallest magnitude of interest in km
11-20	RUPTUR(2)	Horizontal rupture length corresponding to STMG + DLMG
. . .	RUPTUR(MGMX) *	Horizontal rupture length corresponding to MGMX--largest magnitude of interest.

XVI. Rupture Width (down dip)--(8F10.0)--(One or two cards; if MGMX is ≤8, then use only one card; see Figure 17)

Col.		
1-10	RUPW(1)	Rupture width corresponds to STMG--smallest magnitude of interest in km

**For an attenuation relationship valid below the depth cutoff, the program gives the same C (i.e., C_1 and C_2) values for magnitude M_s 8.5 and greater earthquakes.

M_s 'log A + 4.15 (Wyss, 1979)

$M_s \sim M_w$	A	L	w
5.5	224	4.7	4 7
6.0	70.8	8.4	8 4
6.5	224	15	15
7.0	708	27	27
7.5	2240	47	47
8.0	7080	80	80
8.5	22400	180	175
9 0	70800	400	175
9.5	224000	1100	200

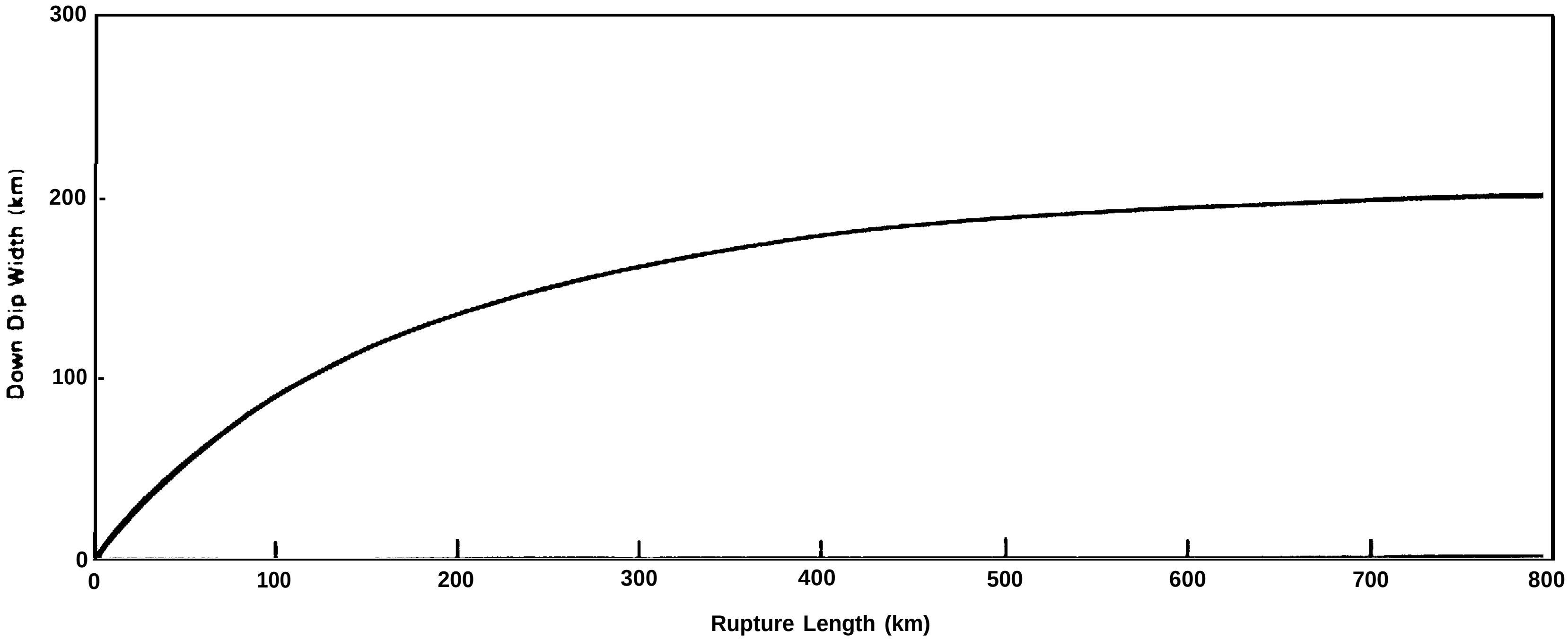


Fig. 17 – Fault Rupture Length Magnitude Relationship

11-20	RUPW (2)	Rupture width corresponding to STMG + DLMG
.	.	.
.	.	.
.	RUPW(MGMX)*	Rupture width corresponding to MGMX -- largest magnitude of interest

XVII . Grid Description--(3 cards per grid)

Card 1--Identification-- (20A4)

Col. 1-80	HED2	Grid identification label

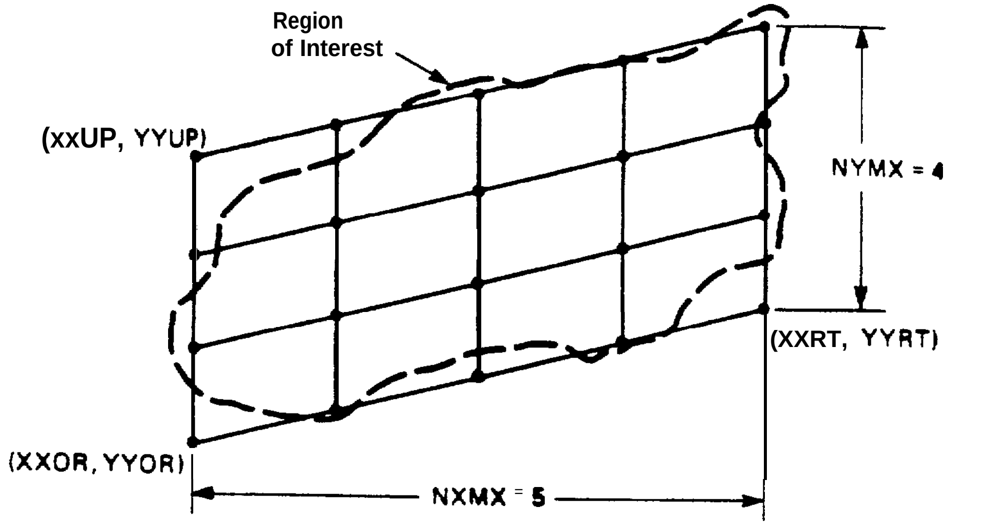
Card 2--Grid Coordinates-- (7F10.0) (See Figure 18)

Col. 1-10	XXOR	X-coordinate of origin, in degrees
11-20	YYOR	Y-coordinate of origin, in degrees
21-30	XXRT	X-coordinate of right bottom corner, in degrees
31-40	YYRT	Y-coordinate of right bottom corner, in degrees
41-50	XXUP	X-coordinate of left top corner, in degrees
51-60	YYUP	Y-coordinate of left top corner, in degrees
61-70	ZZSITE	Depth of site (km)--DEFAULT = 0

Card 3--Grid Coordinates --(415) (also passed to plot file)

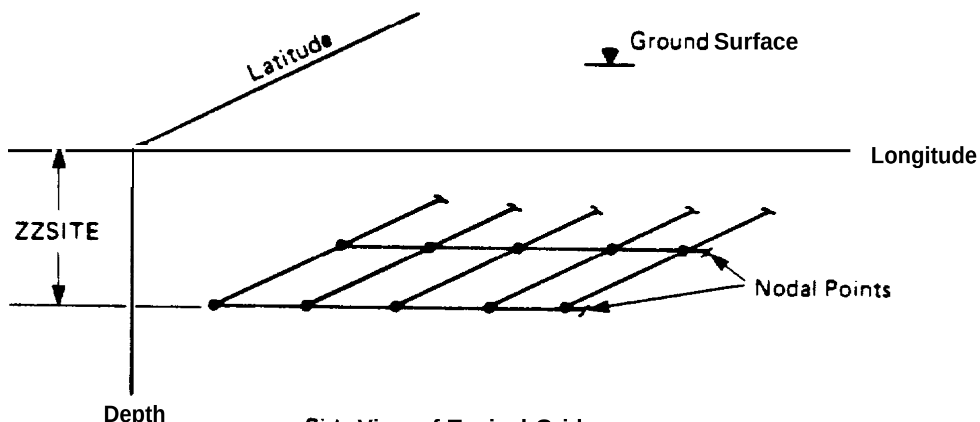
Col. 1-5	NXMX*	Number of points in X direction
6-10	NYMX*	Number of points in Y direction; if (NXMX.EQ.o and .NYMX.EQ.o) only site XXOR, YYOR will be studied

*If rupture RUPW (MGMX) is read as zero, the point-source model is used.



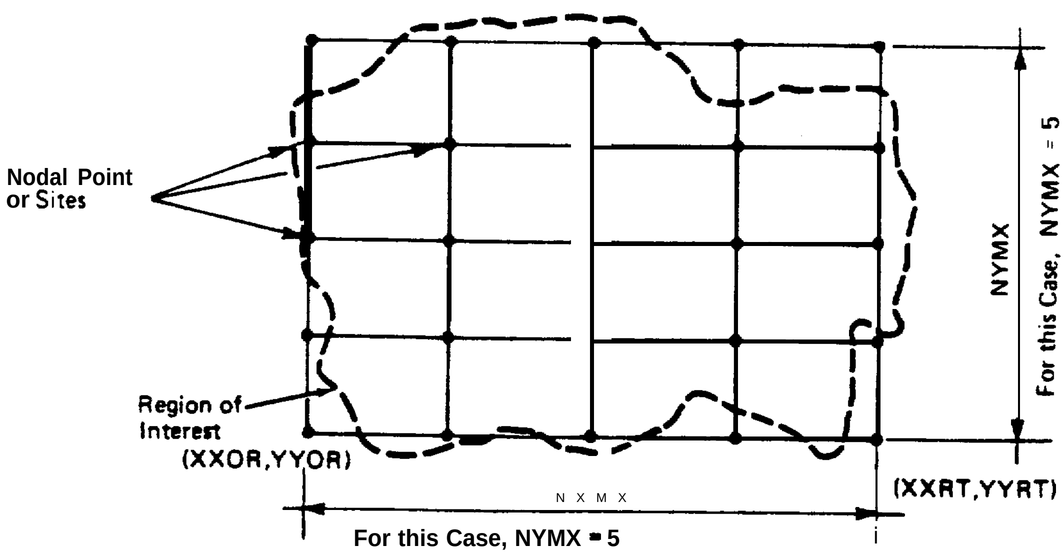
Plan View of Non-Orthogonal Grid

NOTE: The program allows for grids making an angle with the horizontal,
The flexibility when covering a given region is increased with this option.



Side View of Typical Grid

NOTE: ZZSITE is given in kilometers (negative) if zero, nodal points or sites
are assumed at ground surface.



Plan View of Conventional (Orthogonal) Grid

Fig. 18- Options for Grid Configurations

11-15	PLFR	Plot frame? O = NO, used in PLOT.ISO
15-20	SKIPAC	Transform ACC to intensity ? O = NO, used in PLOT.ISO

Note: If (NXMX = O) and (NYMX = O), only one site with coordinates XXOR and YYOR will be studied.

3.2 Entry of Source Geometry Data

Several recommendations that will facilitate data entry and efficient use of the program are summarized in the following paragaphs.

- o The relationship between distances in degrees (input) and in kilometers (used in the analysis) is obtained using algorithms appropriate to the map projections used. The parameters needed to define the respective projections are given below:

  One point of reference from which the distances are computed. All distances should be positive; therefore, this point (XORIG, YORIG) should be chosen at a location near the left bottom corner of the area of interest.

  The coordinate sign convention is north and east as positive; hence, in the sample problems to follow in Section 7.0, the site and sources are located in the northwest quadrant, and the coordinates are, respectively, positive and negative in sign.

- o A number of ground-motion parameters (NOVB), e.g., peak ground acceleration, can be studied in one run. Two attenuation relationships can be used: shallow and deep. The limiting depth for which the shallow relationship is valid should be deeper, or as deep as the deepest node of the shallow sources.

- The output of the program SEISMIC.EXPOSURE can be saved on disk in the standard line-printer format (SAUT = 1) and in a condensed version for later use in plotting (SADT = 1). The output for the first ground-motion parameter is directed to logical unit IWPT (line printer, default = 11) and, as required, to logical units IWUT and IWDT, the line printer copy, and the plotted version, respectively.

  The program increments the value of the logical units by one for each additional ground-motion parameter and creates a different file for each. For example, if three parameters are being studied and all outputs are required, a total of nine files will be created.

- The coordinates of all nodes are entered sequentially. The elements (trapezoids or triangles) are described by their node indices. The elements are entered in the order they are selected in the area sources (i.e., the element of the first source first and so on). The number of elements in each band are entered, starting with the deepest band and moving up to the shallowest band.

- Area sources must be entered first; the line sources follow.

- When entering an area source (Figures 3, 9, 10, 11, and 12), the following conventions should be observed:

    Lines defining bands must be horizontal. In Figure 3, A_1 and A2 are at the same depth:

similarly, B_1 and B_2 are at the same depth. Lines defining bands must also be parallel. Consequently one band will generally contain only one element. If the distance from the right and left corners to the base of the trapezoid differ by more than one vertical integration step, an error message will be printed and the program will terminate. (This is another reason for choosing large vertical integration steps.)

Elements must have a down-dip length greater than one vertical integration step. If the down-dip length is less than two vertical integration steps, the program will run, but a message will be printed.

The indexing of the elements must be sequential in each band (either right to left or left to right) starting with the deepest band and moving to the shallowest (although, as previously stated, it is recommended that each band contain only one element) . Two adjacent bands in a source must share a common side. They must neither overlap or be separated by a gap. The shallow edge of one band must be the deep edge of the next.

If non-zero values are being input as rupture lengths or widths, two consecutive values for incremental earthquake magnitudes should not be within one integration step of each other. The consequence is that one of the checking routines in the program regards the input values for ruptures as zero, thus automatically selecting the point source model even though non-zero rupture lengths are input and a rupture model is desired.

The four boundary conditions are input in the following order: deep, shallow, left side and right side (looking from deep to shallow).

The fault length and down-dip length are related to the rupture length of the largest earthquake that can occur on the fault in the following manner :

If either boundary condition is +1, the fault length must be greater than or equal to 1/2 the rupture length plus one integration step. If it is larger than this value, but smaller than 1/2 the rupture length plus 2 integration steps, the program will run, but a warning will be printed.

If the boundary conditions are O or -1, the fault length must be larger than the rupture length plus 1 integration step. If it is larger than this value but smaller than the rupture length plus 2 integration steps, the program will run, but a warning will be printed.

A warning will be printed if the boundary condition of the top boundary is +1. This is to prevent ruptures which will extend beyond the earth's surface. For gently dipping buried sources, this will not be a problem.

The epsilon value is used by the program in order to identify which are the shallow and deep boundaries of an area source. This parameter must be small relative to the integration step chosen. For example, if the integration step is 1 km, then epsilon should be no larger than 0.1 km.

A triangle is treated as a trapezoid with one edge having zero length. Because of this and the previously discussed constraints on fault lengths, the only rupture than can occur on a triangular source is a point rupture.

A triangular element is described as follows: If there are two deep points and one shallow point it is input as B_1, A2, A_3, B_1. If there is one deep point and two shallow points it is input as B_1, A2, A2, B3 (where B is shallow and A is deep).

o When entering a line source (Figures 14, 15):

All the nodes must be at constant depth.

The nodes must be numbered sequentially along the source , either from left to right or right to left.

The rupture-length boundary condition can be set so that the rupture may extend to include several segments, but will not extend to another line source.

The first boundary condition applies to the side of the line with the smaller node index.

Line sources can contain bends between segments but the program does not work if the angle between segments is acute. It is recommended that the angle between the first and last segments not be less than 135,.

The length of a line segment must be greater than one horizontal integration step.

It is usually simpler to enter a vertical crustal fault as a line source.

3.3 Entry of Source Seismicity Data

Conventions for entering seismicity data are discussed below. In all cases, seismicity distribution on a line source or an area source is treated uniformly over the entire source.

- The rate of occurrence of various earthquake magnitudes is specified for each source.

- Earthquake magnitude intervals (e.g., 0.25) must be uniform for each magnitude interval, from smallest to largest magnitude, for a given source.

- Each earthquake source must have the same minimum magnitude for which the number of earthquakes has been specified.

- If it is desired to include the semi-Markov treatment of earthquake recurrence, the MARKOV program must be executed in order to generate the proper inputs for the sources. The non-semi-Markov earthquake magnitudes are provided up to a cutoff magnitude. The recurrence description is completed when the number of earthquakes, their probability of occurrence, and respective magnitudes are obtained from the MARKOV program run.

- The magnitude interval chosen for the non-semi-Markov magnitude distribution on a given source must be the same as the magnitude interval for the semi-Markov treatment.

- A magnitude state is defined in the semi-Markov treatment as the central magnitude in a given interval. For example, if the non-semi-Markov treatment covers magnitudes up to magnitude 7.55, then the semi-Markov treatment would begin at State 1 (8.05). State 1 represents the number of earthquakes between magnitude 7.8 and 8.29; similarly, State 2 (8.55) represents the magnitude 8.3 to 8.79 interval and State 3 (9.05) represents the magntude 8.8 to 9.29 interval.

3.4 General Comments on Applications

The key task in setting up a given seismic exposure problem for the SEISMIC.EXPOSURE software package is to correctly input all geometry, recurrence, and associated program control inputs. This task can be expedited by using a one-site problem, without doing any computations for probabilities, which will have a relatively short clock run time (say 60 seconds) on the program execution run card. The short run time allows program execution to proceed through reading and writing the input parameters, thus allowing errors to be identified before more costly computation of probabilities.

When using more than 10 sources, it is helpful to make runs using only 4 to 5 sources at a time. Once the input data are verified as being correct, the smaller source data files (card images) can be concatenated to obtain the desired number of sources for the problem. In other applications, it may be more cost-effective to generate just a listing of ground-motion values for selected sites rather than generating a complete plot. Several (13) ground-motion-value parameters can be evaluated from a single run.

If ground-motion-value contribution tables are desired, care must be taken in the selection of table parameters. These parameters determine how much output will be obtained for each site. Computing time and the volume of output obtained increase nonlinearly when contribution tables are generated;

therefore, the assignment of larger size files must be made prior to the run.

The contribution tables provide a source by source breakdown of percentage contribution to seismic exposure values given in the site-by-site probability of exceedance output. The types of contribution tables and their meaning are as follows:

- o source by source detailed listing of percent contribution by magnitude interval to each ground motion level. This presentation allows for the immediate identification of which magnitudes and which sources contribute to the seismic exposure. The total number of earthquakes on all sources that contribute to the exposure is listed.

- o The magnitude-ground motion level-source summary table shows the total number of earthquakes that have generated each ground motion level by source. When these numbers of events are corrected to Poisson probabilities for the selected period of interest, source contributions to the total probability of exceedance can be obtained. These individual source contributions to the total probability of exceedance must be obtained through the numbers of events. They cannot be obtained correctly by merely subtracting probability levels.

The inputs to the **MARKOV** program are discussed in the next section. The remaining two programs, **CONST.PROB** and **PLOT.ISO,** are discussed; the development of two sample problems follow the discussion.

4.0 MARKOV PROGRAM ELEMENTS

A semi -Markov process has been selected to model the patterns of spatial and temporal variations of great earthquakes in a seismic-gap-type environment. A semi-Markov process can be defined as a process in which a system of interest (e.g., occurrences of earthquakes) makes transitions from one state (e.g., one earthquake magnitude) to each of several other states. The transitions are probabilistic and have a one-step memory, i.e., the probability of moving to a given state depends on the present state of the system.

In addition to this property of the more general Markov process, a semi-Markov process is also characterized by a probabilistic holding time between successive transitions. The probability that the holding time between two successive earthquakes is equal to a given value depends on the magnitudes of the two earthquakes. The theoretical development of the model is discussed in the literature (Howard, 1971; Idriss and others, 1979; Patwardhan and others, 1980).

A semi-Markovian representation of earthquake sequences is consistent with the generalized understanding of earthquake generation which consists of a gradual, uniform accumulation and periodic release of significant amounts of strain energy in the earth's crust, as illustrated in Figure 19. The figure shows cumulative strain in arbitrary energy units from an arbitrary beginning time period. Each of the steps in the energy-release curve represents the occurrence of an earthquake of magnitude Mi. Following a great earthquake, the buildup of strain energy sufficient to generate another such earthquake takes time. Therefore, within short periods of time following the occurrence of a great earthquake, the occurrence of another earthquake of similar size at the same location is less likely than the occurrence of one within an area that has not experienced a great earthquake for a long time. As the time without the occurrence of another great earthquake increases, so does the probability of the occurrence of such an earthquake. Therefore, it is reasonable to assume that both the size, M_i, of the next large earthquake and the holding time to that earthquake are influenced by the amount of strain energy released in the previous earthquake (as related to the magnitude of that earthquake) and the length of time or elapsed time, to, over which strain has been accumulating. For instance, assuming a constant strain rate, the strain buildup required to generate a magnitude 8.6 (Ms) earthquake is likely to take longer than the strain buildup required to generate a magnitude 7.8 (Ms) earthquake. These considerations form the basis for the semi-Markovian representation of earthquake sequences used in this work.

4.1 Assessment of Model Parameters

Since the upper range of holding times between large earthquakes may be up to several hundred years, the historical seismicity data alone, of about 80 years, are not sufficient to provide reliable estimates of the parameters of a semi-Markov model; namely, transition probabilities, P_{ij}, and probability distributions of holding times, $h_{ij}(m)$. Therefore, a Bayesian procedure that utilizes both historical seismicity data and subjective inputs of experts in a formal statistical format is used. The details of the Bayesian procedure are discussed in Patwardhan and others (1980).

The required formats for the historical seismicity data and subjective inputs are as follows:

Parameters	Format for Historical Seismicity Data	Format for Subjective Inputs
Transition probabilities	Magnitudes of earthquakes that follow an earthquake of magnitude M_i for each i	Four fractiles (0.25, 0.50, 0.75, 1.0) of the magnitude of the earthquake that follows an earthquake of magnitude M_i for each i
Distribution of holding times	Holding time between two successive earthquakes of magnitude M_i and M_j for each i and j	Four fractiles (0.25, 0.50, 0.75, and 1.0) of the holding time between successive earthquakes of magnitude M_i and M_j for each i and j.

The basis for using the Bayesian approach to developing the required probability distributions and characteristics of these distributions are presented in Section 4.3.

4.2 Main Components of the Semi-Markov Model

The main components of the model can be summarized as follows.

Initial Seismicity Conditions - Initial seismicity conditions define the characteristics of the most recent earthquake having a size in the range included in the model. Two parameters are required: the magnitude of the most recent earthquake, M_o, and the elapsed time, t_o, since the occurrence of that earthquake.

Transition Probabilities, (p_{ij}) - The likelihood that no earthquake of size Mi will be followed by an earthquake of size M_j defines the transition probability, p_{ij}. This is illustrated in Figure 20.

Probability Distribution of Holding Times, $h_{ij}(.)$ - The time between the occurrence of two successive major earthquakes, the first of size M_i and the next of size Mj, is termed the holding time, t_{ij}. The amount of holding time would depend both on Mi and Mj for a given region. The likelihood that tij equals m for all possible values of m defines the probability distribution, h_{ij} (.), of the holding time.

Period of Interest - This is the period, t_p, during which probabilities of occurrences of different size earthquakes are required, for example, a 40-year design life of a structure. These probabilities are a function of real time; that is, for the same time period, t_p, the probabilities depend on the starting time of the analysis.

The subjective probability assessments required by the program MARKOV are in the form of four fractiles (0.25, 0.50, 0.75 and 1.0) of the magnitude of the earthquake that follows an earthquake of magnitude Mi for each i and four fractiles of the holding time between two successive earthquakes of magnitude M_i and Mj for each i and j. The continuous probability distribution defined by the four fractiles of each variable is divided into discrete intervals in the program to obtain the discrete probability distributions $p_{ij}(m)$ and $h_{ij}(m)$.

A fractile of a random variable, x, refers to a point on the cumulative distribution function (CDF) of x. For example, 0.25 fractile of x refers to the value of x such that the probability of being less than or equal to that value is 0.25.

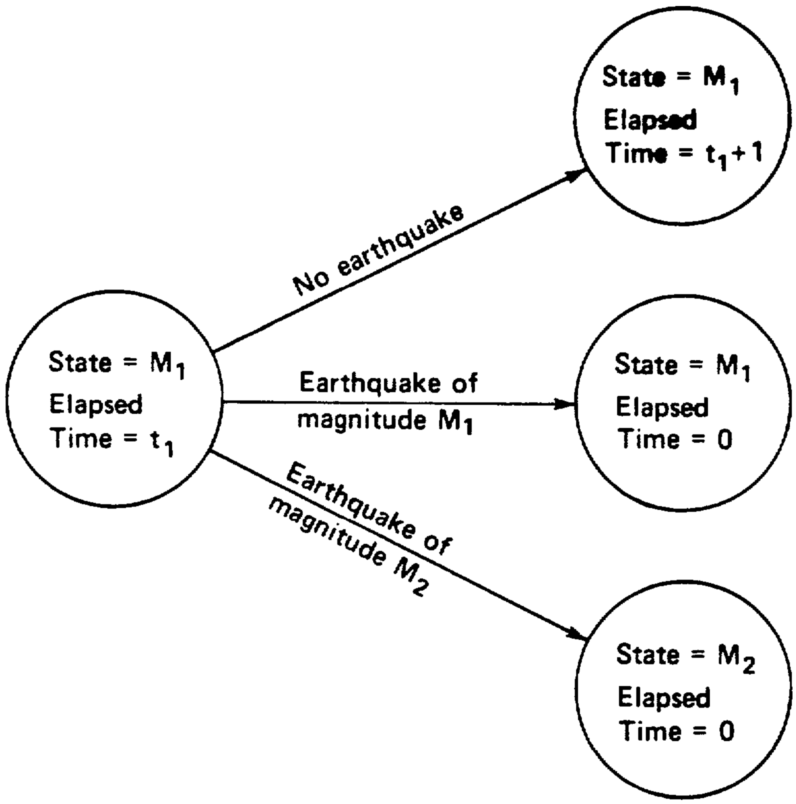


Fig. 20 – Schematic of Semi-Markow State Transitions

Procedures for fractiles of random variables are well established (see, for example, Raiffa, 1968). A procedure appropriate for the assessments required in this program is described in Appendix C.

4.3 Discussion

It should be noted that both the data and subjective inputs define continuous probability distributions of each pertinent random variable. These two distributions are combined to obtain a Bayesian distribution of each variable. This continuous distribution is then divided into discrete intervals within the program MARKOV to obtain the discrete probability distributions, P_{ij} and $h_{ij}(m)$, mentioned in the last section. The forms of probability distributions assumed in the Bayesian analysis are summarized in Table 1.

4.4 Input Data

Input data for the program MARKOV can be entered either on cards or in data files. The following paragraphs describe the data to be entered on 12 cards or equivalent data card images.

I. Run Identification -- (20A4) - One Card

Col. 1-80	RUN(I)	Identification label, I=1 to 20

II. Run Parameters -- (12, 2X, 3F10. 0) - One Card

Col. 1-2	NZONE	Number of zones, DEFAULT=1
6-15	TDELTA	Time increment in years, DEFAULT=5.0
16-25	FCAST	Period of interest, DEFAULT=40.0
26-35	MDELTA	Magnitude increment, DEFAULT=0.25

The above information, items I and II, is applicable to all zones. The following information must be supplied for each of the NZONE zones in sequence, i.e., Zone 1, Zone 2, and so on.

III. Zone Identification -- (20A4) - One Card

Col. 1-80	ZONE (I)	Zone heading, I=1 to 20

IV. Initial Seismicity Conditions -- (11, 14, A4, 1X, 3F10.0) - One to three cards

Card 1

Col. 1	NSTATE	Number of semi-Markov magnitudes to be generated maximum = 4, no DEFAULT
2-5	NSEG	Number of segments. This allows user to proportion seismicity between segments of a zone. The appropriate proportions are input in Card 2. If NSEG = 1, Card 2 is not input. Maximum of 20 segments are allowed.
6-9	FILE	If FILE is blank, the output is written to printer only. If FILE is not blank, output will be written to file number specified in Card 3. Card 3 is not input if FILE is blank.
11-20	GAP	Number of years since last earthquake, no DEFAULT
21-30	MAG	Magnitude of last earthquake, no DEFAULT
31-40	MAG1	Magnitude of first semi-Markov magnitude, no DEFAULT

TABLE 1

FORMS OF PROBABILITY DISTRIBUTIONS
ASSUMED IN THE BAYESIAN ANALYSIS

Variable	Data Distribution	Prior (and Posterior) Distribution of Parameters	Bayesian Distribution of Variable
Holding Time, t_{ij}	Distribution of in t_{ij} is normal	Distribution of and ^{2} of in t_{ij} is normal-inverted-gamma-2 (parameters of this distribution obtained by fitting an empirical equation to the four, subjectively assessed fratiles).	Distribution of in t_{ij} is student-t (this distribution is broken into discrete intervals to obtain h_{ij} m).
Magnitude, Mi of an Earthquake Following an Earthquake in State i	Distribution of in (M_i - M*) is normal.	Distribution of and ^{2} of in (Mi - M*) is normal-inverted-gamma-2.	Distribution of in (Mi - M*) is student-t (this distribution is broken into discrete intervals to obtain P_{ij}).

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DEVELOPMENT AND INITIAL APPLICATION OF SOFTWARE FOR SEISMIC EXPOSURE EVALUATION

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Table 1, col. 3 should be:

Distribution of μ and σ^2 of in t_{ij} ...

and

Distribution of μ and σ^2 of in $(M_i - M^*)$...

Card 2	(NSEG)F10.0	Not input if NSEG = 1
Col. 1-10	PROP(1)	The proportion of the seismicity
11-20	PROP(2)	to be assigned to segment 1, 2,
:	PROP(NSEG)	etc., could be based on area or other user determined criteria. The sum of PROP's should equal 1.

Card 3	NSEG (I)	Not input if FILE is blank.
Col. 1-4	OUT(1)	Output unit number for segment 1 of zone if NSEG=1
5-8	OUT(2)	Output unit number for segment 2
	⋮	⋮
.	OUT(NSEG)	Output unit number of segment NSEG

V. Data for each Magnitude of Model within Zone NSTATE Card Groups

Card 1	(20 A4)	
Col. 1-80	Title (I)	Parameter description, labeled as M_1, M_2..., M_n where n . STATE .

Card 2 (12)

Col. 1-2 N Number of data points, 0=none

Card 3	(8F10.0) --	Only Read if N½0
Col. 1-10	Y(l)	1st data point
11-20	Y(2)	2nd data point
:	:	:
71-80	Y(8)	8th data point

Repeat until the Nth data point is specified. Total number of cards = (N+7)/8 truncated

Card 4 Int (N+7)8 +2 (A4, 6X, 4F10.0)

1-4	PFLAG	Flag for prior data. All 4 columns blank means no prior data. Otherwise, prior data will be read.
11-20	PRIOR(1)	25% fractile
21-30	PRIOR(2)	50% fractile
31-40	PRIOR(3)	75% fractile
41-50	PRIOR(4)	100% fractile, maximum

VI. Data on Holding Times - (NSTATE**2 card groups corresponding to the NSTATE**2 holding times)

Card 1 (20A4)

Col. 1-80 TITLE(I) Parameter description labeled as T_{11}, meaning the holding time between magnitude (1) and magnitude (l); T_{12}, the holding time between magnitude (1) and magnitude (2); and so on for subsequent groups (NSTATE*NSTATE) of holding time cards.

Card 2 (12)

Col. 1-2 N Number of data points, O=None

Card 3 (8F10.0) - Only Read if N½O

Col. 1-10	Y(1)	1st data point
11-20	Y(2)	2nd data point
:	:	:
71-80	(8)	8th data point

Note: Repeat until the Nth data point is specified.
Total number of cards = (N+7)/8 truncated.

Card 4 (A4, 6X, 4F10.0)

Col. 1-4	PFLAG	Flag for prior data. All 4 columns blank means no prior data. Otherwise, prior data will be read.
11-20	PRIOR(1)	25% fractile
21-30	PRIOR(2)	50% fractile
31-40	PRIOR(3)	75% fractile
41-50	PRIOR(4)	100% fractile

Note:

The parameters of the model must be entered in the following sequence:

A. The first NSTATE card groups correspond to the NSTATE magnitudes in increasing order.

B. The remaining NSTATE2 card groups correspond to the NSTATE2 holding times. They are entered in this order:

1. Holding time between magnitude (1) and magnitude (1)
2. Holding time between magnitude (1) and magnitude (2)

:

NSTATE Holding time between magnitude (1) and magnitude (NSTATE)

NSTATE+1 Holding time between magnitude (2) and magnitude (1)

NSTATE+2 Holding time between magnitude (2) and magnitude (2)

*NSTATE Holding time between magnitude (2) and magnitude (NSTATE)

:

NSTATE2 Holding time magnitude (NSTATE) and magnitude (NSTATE)

C. It is permissible to have no data points or no prior data, but one of the two must be provided.

D. PRIOR(4) ≥ PRIOR(3) ≥ PRIOR(2) ≥ PRIOR(1) and PRIOR (4) > PRIOR(1) > 0 For magnitudes, PRIOR(4) ≤ 9.0

E. Data values > 0. For magnitudes, each data value ≤ 9.0.

F. Zero and 4 blanks are not the same with respect to DFLAG.

G. In a multi-zone run, the next zone heading follows the last parameter specification of the previous zone.

H. If more than one zone is to be written to the same output file, the order must match the order in which the zones are read in SEISMIC.EXPOSURE.

4.5 Program Output

The program output is printed on the line printer and is also saved on file for the purpose of providing input data to the program SEISMIC.EXPOSURE. Due to the size of typical subduction zone sources and the varying dips of a given source, it may be necessary to divide the source into segments. These segments have seismicity and probabilities that are proportioned accordingly in the MARKOV program. This partitioning is based upon the percent of area contained within each segment. The proportions should sum to 1.0 (i.e., 100 percent).

Therefore, the proper number of output files need to be assigned and referred to in subsequent processing in the same order; that is, the order and segment naming convention must be maintained for the source characterization in the program SEISMIC.EXPOSURE for magnitudes less than or equal to the cut-off magnitude.

The next section discusses the output from the SEISMIC. EXPOSURE program that is processed by the CONST.PROB program. This program computes user-selected levels of ground-motion parameter values that are estimated to be met or exceeded at least once over the user-specified period of interest.

5.0 CONST. PROB PROGRAM ELEMENTS

5.1 Description of the Program

The probabilities of exceedance for a given ground-motion parameter(s) and for a given time period of interest, "t", have been determined through the use of the program SEISMIC. EXPOSURE and/or MARKOV. Probabilities of exceedance have been obtained in the form of a complementary cumulative distribution function (1-CDF). This has been done for one or several sites (or nodal points) within a given region, depending on the desired outcome of the analysis.

The next step in the analysis is to generate a seismic exposure map by selecting the value of the ground-motion parameter that corresponds to a given probability of non-exceedance. The program CONST.PROB takes a user-specified probability of exceedance for a given period of time and selects the appropriate ground-motion variable.

5.2 Data Input and Program Output

Using the discretized CDF at a site (or sites) and linear interpolation, the program CONST.PROB determines the ground-motion parameter value corresponding to the level of non-exceedance chosen. The procedure is summarized in Figure 21.

In its present form, the program CONST.PROB has been organized into a main program containing 67 executable FORTRAN statements with an approximate 71,100 byte (space requirement in core). The program can handle up to 300 nodal points (or sites) and seven levels of exceedance in one run.

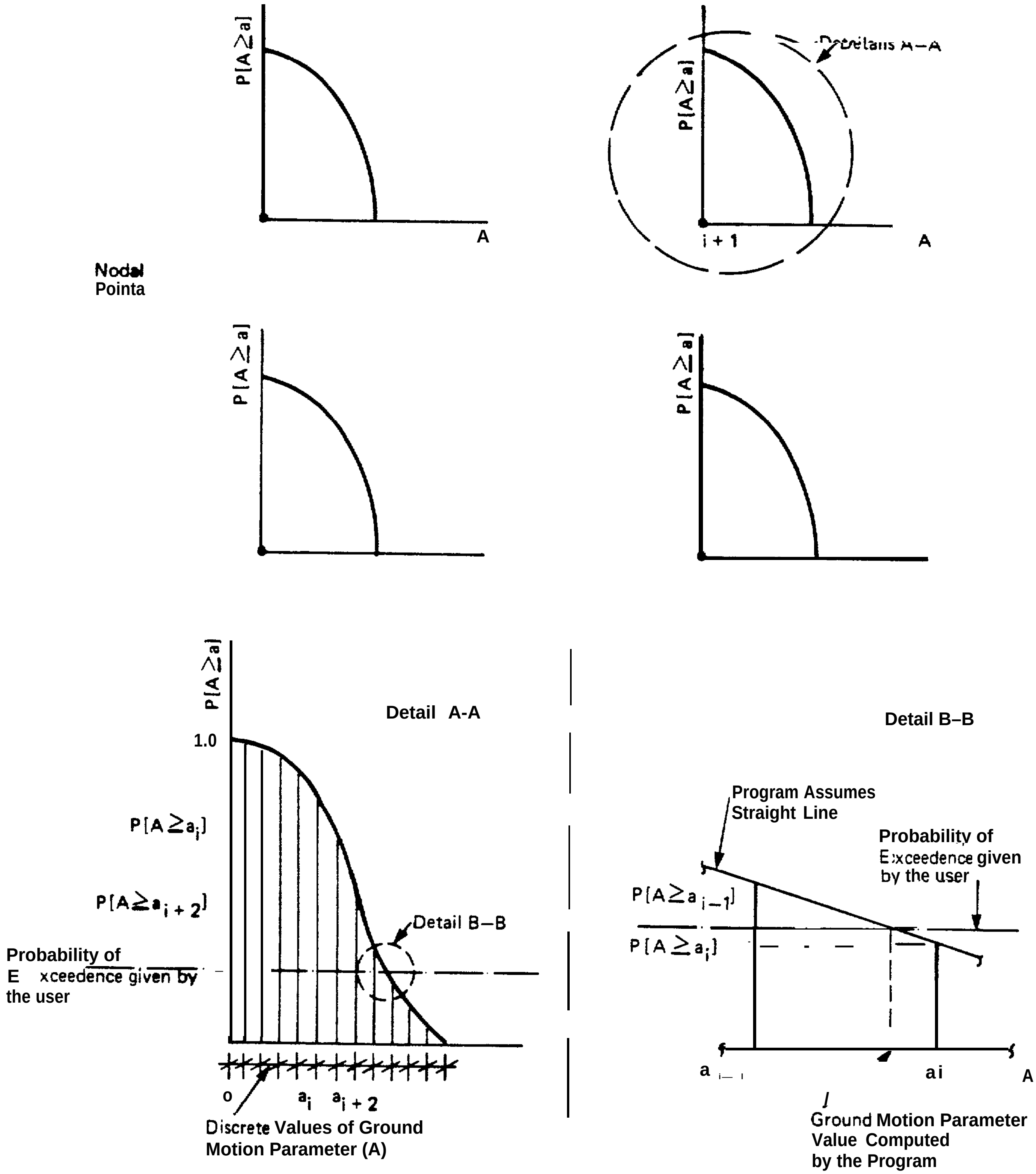


Fig. 21 – The CDF 's or (1 –CDF's) as Computed by the Program CONST. PROB for a Given Grid Ground Motion Parameter (A), and Time Period of Interest "t".

Input data for the program CONST.PROB consists of 11 sets of cards or lines of data file input. The organization of data on each card, along with a description of the items and program output, is given in the following paragraphs:

I. Exceedance Level Information-- (215 .7 F10.0)--One card (this card is read from unit 5).*

Col. 1-10	NOPD	No. of runs required
6-10	NOLV	No. of levels of exceedance in each
11-20	PBLV(1)	First level of exceedance
21-30	PBLV(2)	Second level of exceedance
:		:
71-80	PBLV(7)	Seventh level of exceedance

II. Plot Parameters--(315)--One card

Col. 1-5	NOTP	No. of cards
6-10	I CAL	Plotter size 11 for n-inch Cal Comp plotter 30 for 30-inch Cal Comp plotter
11-15	NN	Plot projection If=0 Lambert conformal projection with one standard latitude projection If=1 Lambert conformal projection with two standard latitudes If=2 Transverse mercator projection with standard longitude only

*The remaining cards can be input from unit IIN(=9) as created by the program SEISMIC.EXPOSURE (SADT=1).

III. Lambert Projection*-- (4F10.0) --One card

Col.	1-10	STL1	Standard latitude 1
	11-20	STL2	Standard latitude 2; if zero, only one standard latitude will be used
	21-30	STLN	Standard longitude
	31-40	SCAL	Scale = 1/SCAL
	41-50	DTLB	Distance between grid marks and label DEFAULT = 0.5 inches

IV. Label Description**-- (7F10.0] --One card

Col.	1-10	DXCR	X-distance between marks (degrees)
	11-20	DYCR	Y-distance between marks (degrees)
	21-30	DXLB	X-distance between labels (degrees)
	31-40	DYLB	Y-distance between labels (degrees)
	41-50	DCLV	Increments between contours
	51-60	XMDC	Label every XMDC contour
	61-70	CRCR	Marks inside grid? If 0 = NO.

V. Run Identification***-- (20A4) --Two cards

Card 1

Col. 1-80 HED1 Identification

*Same parameters as in Data Entry III (Program SEISMIC. EXPOSURE in Section 3.1).

**Parameters used for plotting purposes (to be discussed in Section 6.2).

***Note that Data Sets V-VIII inclusive can be read from Unit IIN (see Macro Flow Chart) as created by program SEISMIC. EXPOSURE.

Card 2

Col. 1-80	HED1	Identification

VI. Variable Identification-- (5A4, F10.0)--One card

Col. 1-20	HED2	Variable identification; e.g., acceleration
21-30	VBPR	Variable increment: step increment of ground-motion parameter, e.g., 20 cm/sec^2 for peak acceleration

VII. Grid Identification- (20A4)--One card

Col. 1-80	HED3	Grid identification label

VIII. Grid Description-- (2I5, 6F10.0)--One card

Col. 1-10	XXOR	X-coordinate of origin
11-20	YYOR	Y-coordinate of origin
21-30	XXRT	X-coordinate of bottom right corner
31-40	YYRT	Y-coordinate of bottom right corner
41-50	XXUP	X-coordinate of top left corner
51-60	YYUP	Y-coordinate of top left corner

IX. Plot Flags--(2F10.0, 215)

Col. 1-10	NXMX	Number of points in X-direction
11-20	NYMX	Number of points in Y-direction
21-25	PLFR	Plot Frame? If 0 = NO.
26-30	SKIPAC	Transformation from acceleration to intensity? If 0 = NO.

X. Number of Values in CDF (or 1-CDF)--(15) --One card

Col. 1-5	NOVB	Number of values in CDF (i.e., 40)

XI. CDF Levels of Exceedance-- (10F8.0) --(NXMX*NYMX) cards or set of cards

Col. 1-10	PB(1)	Probability of exceedance corresponding to the smallest ground-motion parameter value
	⋮	⋮
	PB( )	
	PB(NOVB)	Probability of exceedance corresponding to the largest ground-motion parameter value

Note: The Do-Loop on NOPD (number of runs required) starts at Data Entry V above.

The output from the program CONST.PROB consists of the values of ground-motion parameters that have a given probability of non-exceedance. This output is displayed on the 'line printer as well as stored on file for later use in the program PLOT.ISO; it generates the contours of ground-motion values and outputs them to a file for plotting (see Figure 8).

6.0 PLOT.ISO PROGRAM ELEMENTS

6.1 Description of the Program

Preparation of a seismic exposure map using the program PLOT.ISO is discussed followed by sections discussing two sample problems, one without semi-Markov inputs and a second that uses semi-Markov inputs. The program PLOT.ISO selects the minimum and maximum values of the specific ground-motion parameter of interest from the data obtained by program CONST.PROB and computes the number of contours to be plotted on the basis of the parameter selected by the user. A second-order polynomial is used to interpolate between the ground-motion parameter values at the grid's nodes in order to establish the locus of points corresponding to each contour. The data output from CONST.PROB can be used with a user-supplied contour plotting routine if so desired.

When contours are not uniquely defined (in the case where four points are at the same level within a quadrangle see Figure 22), the program draws the contour so that the change in slope is minimum and prints a message (FOURPT call number) . If, after inspection of the plot, it appears that the other choice should have been made, the flag (NBCL--see Data Entries VI and VII) for that FOURPT call number should be set and the program re-run. The contour corresponding to the largest slope variation will then be drawn. The macro-flow chart for program PLOT.ISO is shown in Figure B-4.

A file containing contour information is created that can be previewed with a CRT and plotted on the 11- or 33-inch Calcomp plotter. Three plot options are available: Lambert Conformal Conic projections 1 and 2 and Transverse Mercator. The program has the optional capability of converting the ground-motion parameter peak acceleration into intensity using

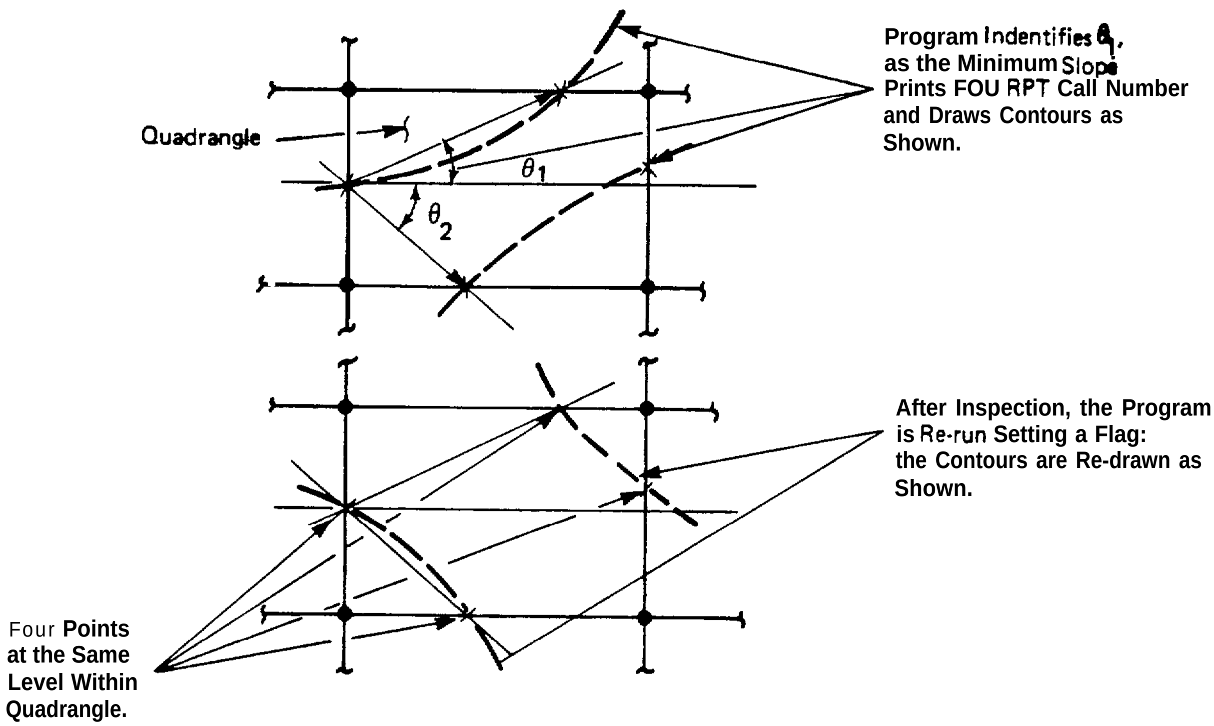


Fig. 22 - Case where Contour is not Uniquely Defined

Richter-Gutenberg's relation I = 3(LOG peak acceleration + 0.5). This option can be specified by setting the parameter "SKIPAC" to a value different from zero in the input data deck (data file).

The program PLOT.ISO has been developed so that only standard CalComp calls are used. A maximum of 1600 levels for the ground-motion parameter values per grid (i.e., a grid having 40 rows and 40 columns of 1600 sites) are presently accommodated by the program. The program handles any number of different grids per run.

6.2 Data Input and Program Output

Input data for the program PLOT.ISO consists of eight sets of cards (or lines in a data file). These can be read directly from files created by program CONST.PROB. The organization of data on each card and job control statement, along with a description of the data entry items, are given in the following paragraphs:

A. Input Unit Number

Col.	1-5	IIN	Unit number for input data

I. Identification Card-- (3I5, 16A4) --One card

Col.	1-5	NOTP	Number of plot types; i.e., different grids
	6-10	I CAL	Plotter size: 11 for n-inch size (default), 30 for 30-inch size
	11-15	IPROJ	Flag for Lambert projection, 0 = 0/180,, 1 = 0/360,, 2 = Transverse Mercator

	16-80	HED1	Run identification

II. Lambert Projection-- (5F10.0)--One card

Col.	1-10	STLT1	Standard latitude 1
	11-20	STLT2	Standard latitude 2; if read as zero, will use only one standard latitude
	21-30	STLN	Standard longitude
	31-40	SCAL	Scale (1/SCAL)
	41-50	DTLB	Distance between grid and label Default = 0.5 inch

III. Plot Flags-- (5I5) --One card

Col.	1-5	NOPL	Number of plots with same parameters
	6-10	NXMX	Number of points in X-direction; i.e., number of columns in grid
	11-15	NYMX	Number of points in Y-direction; i.e., number of rows in grid
	16-20	PLFR	Plot frame, If 0 = NO
	21-25	SKIPAC	Conversion from acceleration to intensity, If 0 = NO

IV. Grid Description--(6F10.0) --One card (see Figure 23)

Col.	1-10	XXOR	X-coordinate, of origin
	11-20	YYOR	Y-coordinate, of origin
	21-30	XXRT	X-coordinate, of right bottom corner
	31-40	YYRT	Y-coordinate, of right bottom corner
	41-50	XXUP	X-coordinate, of left top corner
	51-60	YYUP	Y-coordinate, of left top corner

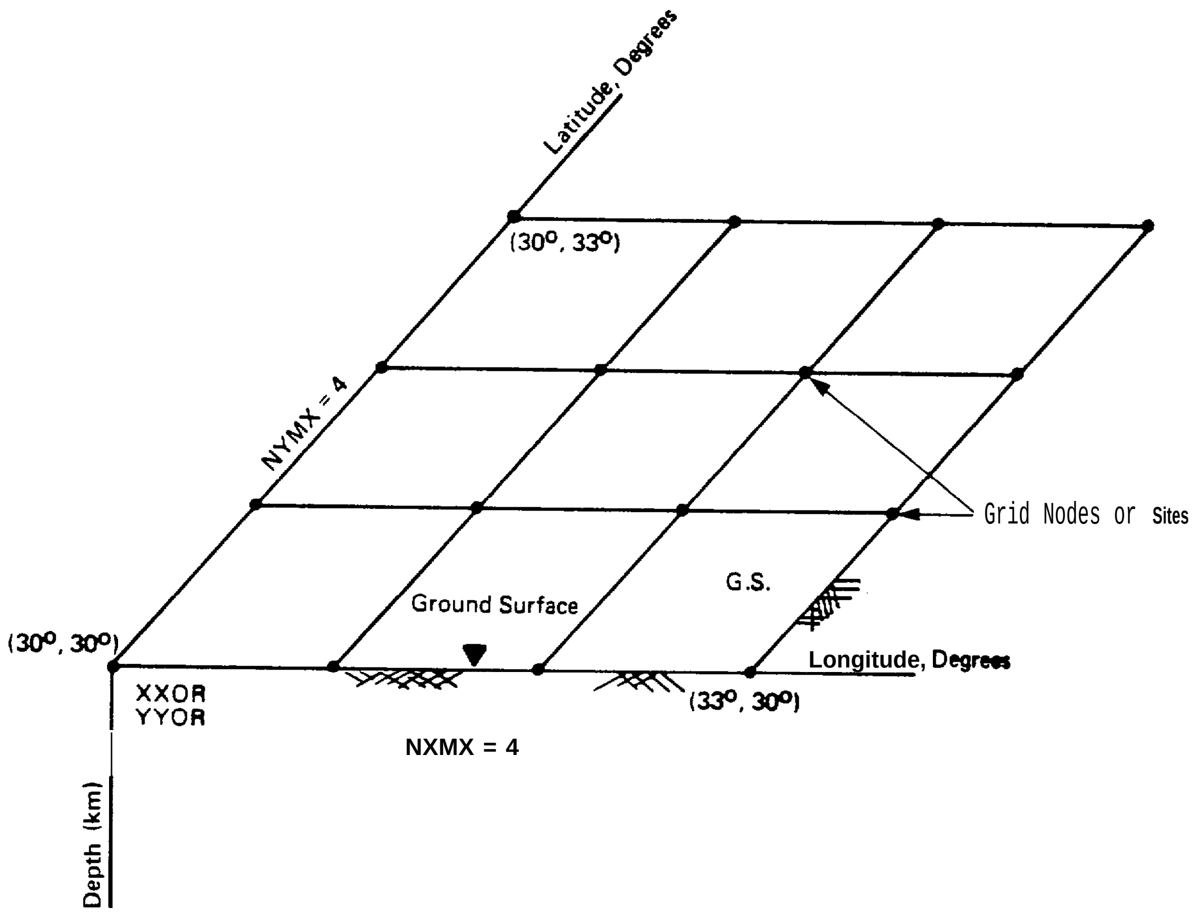


Fig. 23- Typical Grid for Sample Problem 1

V. Label Description-- (7F10.0)--One card

Col.	1-10	DXCR	X-distance between marks, degrees
	11-20	DYCR	Y-distance between marks, degrees
	21-30	DXLB	X-distance between labels, degrees
	31-40	DYLB	Y-distance between labels, degrees
	41-50	DCLV	Increments between contours
	51-60	XMDC	Label every "XMDC" contour
	61-70	CRCR	Degree marks inside grid? If 0 = NO

VI. Plot Identification-- (75A1, 15)--One card

Col.	1-75	HED1	Title of plot
	76-80	NOMD	Number of modifications in FOURPT

VII. Calls Needing Modifications--(16I5) --16 values per card (input only if NOMD # 0; see Figure 22)

Col.	1-5	NBCL(1)	First FOURPT call needing modification
	6-10	NBCL(2)	Second FOURPT call needing modification
	⋮	⋮	⋮
		NBCL(NOMD)	Last FOURPT call needing modification

VIII. Ground-Motion Parameter Values at Grid Nodes*-- (8F10.0) --8 values/card). Repeat "NYMX" times; read data in by rows (Figure 23).

Col.		
1-10	AA(1,1)	Ground-motion parameter value at origin of grid
11-20	AA(1,2)	Ground-motion parameter value at right of origin
.	.	.
	AA(1,NXMX)	Ground-motion parameter value set at XXRT, YYRT

Note: The do-loop on NOPL starts at Data Entry V above; if "DCLV" is different between two plots, the do-loop has to be done on NOTP, starting at Data Entry II above.

The next section discusses two sample problems that illustrate the input and output from the various programs required to generate seismic exposure maps.

*These values correspond to the output produced by program CONST.PROB (i.e., ground parameter's values obtained for a given probability of exceedance or non-exceedance 1 - P (exceedance) and time period t for an entire set of nodal points or sites).

7.0 SAMPLE PROBLEMS

Two sample problems are discussed in this section. The first has no inputs for great earthquakes Ms 7.8, which would require use of the semi-Markov model. The problem consists of six earthquake sources in a region of interest (shown in Figure 9) for which the seismic exposure is to be determined at several sites for the 5-percent level of exceedance in a 50-year time period. The necessary program inputs for source geometry, earthquake recurrence, rupture-length-magnitude information, attenuation, and plot information are discussed.

The first discussion of the problem deals with the basic set-up information that goes into the program SEISMIC.EXPOSURE. The second section discusses output from SEISMIC.EXPOSURE and the program inputs for the program CONST.PROB, which selects the levels of exceedance for ground-motion parameters. The last section discusses the input and output of the program PLOT.ISO, the contour plotting routine for generation of seismic exposure maps.

The second problem illustrates the capability of the program SEISMIC.EXPOSURE to handle seismic gaps. The problem consists of four area sources in a subduction-zone-type tectonic environment, and one line source, for which seismic exposure is to be determined at one site. Because seismic gaps and large earthquakes are to be considered, a semi-Markov simulation must be completed in the program MARKOV before executing the SEISMIC.EXPOSURE program to obtain ground-motion values.

7.1. Program SEISMIC.EXPOSURE - Sample Problem 1

The region of interest is shown in Figure 9. Earthquakes have been assigned to the faults in the region by taking into consideration knowledge of geology and the historical earthquake records for the region. The earthquake sources consist of an Area Source 1, Line Source 1, and Area Source 2. A seismic exposure map showing peak acceleration contours is desired that has a 5-percent probability of exceedance (or 95-percent probability of non-exceedance) over the next 50 years. Using the fault locations on the base map, the latitudes and longitudes of the nodal points identifying each earthquake source are tabulated along with focal depths of the respective nodal points. Figure 14 shows the details of the source geometries and their relation to the X-Y grid coordinate system of Figure 23.

Recurrence information for the three earthquake sources is obtained in a three-step process:*

1. Develop the recurrence input beginning with the association of a magnitude-frequency relation with each source (Figure 24). From the relation, a distribution of the number of earthquakes is selected, with magnitudes M_i (e.g., 0.25 magnitude units) above a minimum magnitude (e.g., M = 3.5). Additionally, if semi-Markov simulation input for large magnitude earthquakes is desired, separate inputs must be developed in the MARKOV program and entered into the program SEISMIC.EXPOSURE. From these results, the rate of occurrence of events, independent of magnitude

*Recurrence information is entered for a subduction-zone source as for any other source up to a cut-off magnitude. Above that magnitude, the SEISMIC.EXPOSURE program will enter the number of events obtained from the semi-Markov inputs. This procedure will be discussed in detail in the second sample problem.

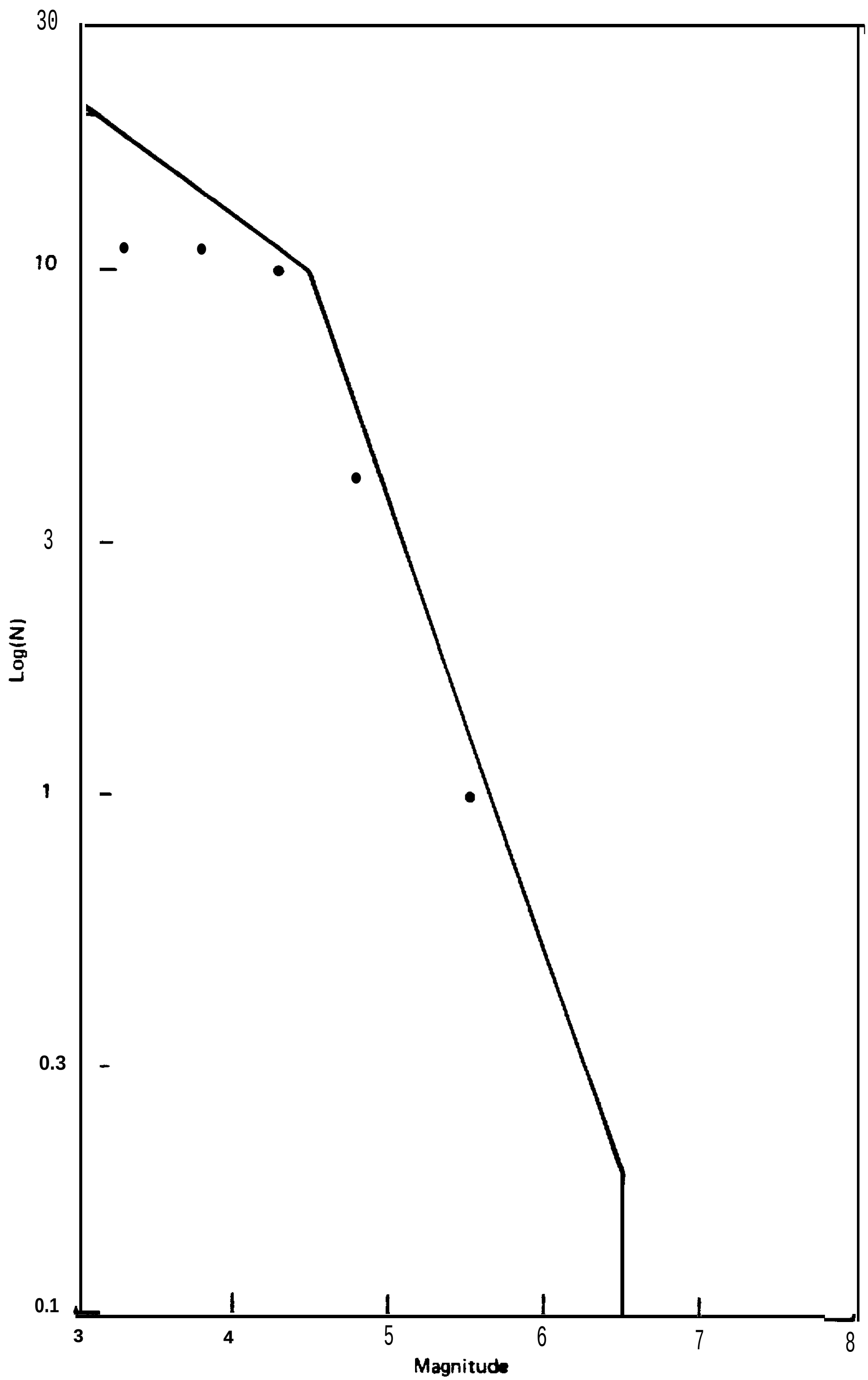


Fig. 24 -Recurrence Relationship for Line Source 1

and respective probabilities, are determined in the program using the Poisson-Gamma model of earthquake occurrence.

2. Information pertaining to the distribution of magnitudes of the events Mi must be compiled for input into the Bernoulli-Beta model on magnitude distribution. For each M_i, the probability of success is determined for each trial. A trial is defined as the occurrence of an earthquake. A success is the occurrence of an earthquake of magnitude M_i, and a failure is the occurrence of an earthquake of any other magnitude. These data are summarized in Tables 2 through 4 for the three sources shown in Figure 9.

The above inputs allow for information to be entered into the seismic exposure evaluation process from two sources through a Bayesian analysis: historical earthquake data and subjective inputs based on geologic and seismologic information. Specific inputs for the Poisson, Bernoulli, attenuation, and rupture-length\magnitude elements of the analysis are discussed below.

7.1.1 Earthquake Recurrence Data - Poisson Model

In following the description of program inputs found in Woodward-Clyde (1978), Guidi (1979), and Mortgat and Shah (1979), the generating process for the mean number of occurrences is the Poisson model with mean rate of occurrence λ. The parameter λ is treated as a random variable with uncertainty; Bayesian statistics are applied; and λ is chosen to have a Gamma distribution (see Figure 5).

TABLE 2

RECURRENCE DATA FOR LINE SOURCE I

As obtained from the historical earthquake data and geologic history information

υ'' is a parameter of the posterior distribution

υ'' corresponding to XNBDAT(IXSC)* in Data Set XI card 5 and Data Set XII, card 3.

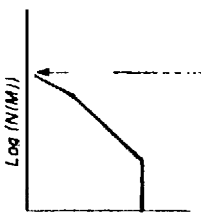
Time Data Base (T) : 50
Number of Recorded Events (N) : 12

υ' from log-linear fit: 16

$\lambda'' = \lambda' + T = 50 + 50 = 100$

$\upsilon'' = \upsilon' + N = 16 + 12 = 28$

$\eta''_{M_i} = \eta'_{M_i} + N = 16 + 12 = 28$



Recurrence Relationship (see Fig 24)

υ' is a parameter of the prior distribution on A and sd is the total number of earthquakes greater or equal m magnitude 35 (m this easel expected to occur on the source.

4'' is a parameter of the posterior distribution on λ.
λ' is a parameter of the prior distribution on λ
Nom thatin this particular case, $\lambda' = T = 50$ yrs, implying that the subjective information of the user has the same weight as the available dam.

λ'' Corresponds m TMDA(IXSC)* m Data Set XI. Card 5, and Data Set XII, Card 3.

Richter Magnitude (M_i)	No. of Recorded Occurences in M_i bands (R_{M_i})	Cumulative No. of Occurences (log linear fit Fig. 26) [N_i]	No. of Occurrences M_i Bands (log linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
3.50	1	16.0	2.0	3.0
3.75	1	14.(3	91.5	2.5
4.0	0	12.5	1.5	1.5
4.25	1	11.0	3.0	4.0
4.50	3	9.0	2.6	5.6
4.75	1	5.4	2.0	3.0
5.0	1	3.4	1.3	2.3
5.25	2	2.1	0.8	2.8
5.50	2	1.3	0.'s	2.5
5.75	0	().H	0.J	0.3
6.0		0.5	0.19	0.19
6.25		0).31	0.11	0.11
6.50		0.20	0.20	0.20
6.15				

NB (number of different magnitudes) = 13 (see Data Sets VII and IX).

Difference between successive M bands

Parameter of the posterior distribution on PM

Parameter of the prior distribution on PM

ξ''_{M_i} corresponds to XNBMG (IXSC) in Data Set XI, Card 5 and Data Set XII, Card 3 **

Cuttoff magnitude for obtained from geologic considerations

As read horn Recurrence Relationship (fig 24)

Obtained by adding Columns 2 and 4

*Parameters of Poisson Model
**Parameter of Bernoulli Model

TABLE 3
RECURRENCE DATA FOR AREA SOURCE 1

Time Data Base (T): 125
Number of Recorded Events (N): 5
ν' from log-linear fit: 16
$\lambda'' = \lambda' + T = 125 + 125 = 250$
$\nu'' = \nu' + N = 10 + 5 = 15$
$\eta''_{M_i} = \eta'_{M_i} + N = 10 + 5 = 15$

Richter Magnitude (M_i)	No. of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative No. of Occurrences (log linear fit) (N_c)	No. of Occurrences M_i bands (log linear fit) (ξ'_{M_i})	$\xi'_{M_i} + R_{M_i}$ (ξ''_{M_i})
3.50	0	10.0	2.4	2.4
3.75	1	7.6	1.6	2.6
4.0	0	6.0	1.5	1.5
4.25	1	4.5	1.10	2.1
4.50	0	3.4	0.80	0.8
4.75	1	2.6	0.60	1.6
5.0	1	2.0	0.50	1.5
5.25	0	1.5	0.40	0.4
5.50	1	1.10	0.25	1.25
5.75		0.85	0.21	0.21
6.0		0.64	0.16	0.15
6.25		0.48	0.11	0011
6.50		0.37	0.37	0.37

TABLE 4
RECURRENCE DATA FOR AREA SOURCE 2

Time Data Base (T): 125
Number of Recorded Events (N): 17
ν' from log-linear fit: 21.5

$\lambda'' = \lambda' + T = 125 + 125 = 250$

$\nu'' = \nu' + N = 21.5 + 17 = 38.5$

$\eta''_{M_i} = \eta'_{M_i} + N = 21.5 + 17 = 38.5$

Richter Magnitude (M_i)	No. of Recorded Occurrences in M_i bands (R_{M_i})	Cumulative No. of Occurrences (log linear fit) (N_c)	No. of Occurrences Mi bands (log linear fit) (ξ'_{M_i})	ξ'_{M_i} + ' M_i (ξ''_{M_i})
3.50	1	21.5	3.5	4.5
3.75	0	18.0	2.5	2.5
4.0	2	15.5	2.5	4.5
4.25	3	13.0	2.0	5.0
4.50	3	11.0	1.5	4.5
4.75	0	9.5	1.4	1.4
5.0	3	8.1	3.8	6.8
5.25	2	4*3	2.1	4.1
5.50	3	2.2	1.05	4.05
5.75	0	0.58	0.28	0.28
6.0	0	0.30	0.15	0.15
6.25		0.15	0.15	0.15

The sample likelihood function on λ is derived from the Poisson process. Available historical earthquake data for the region determines the parameters T, the time period of the data base, and N, the number of events greater than a fixed lower bound magnitude during the time period, T. In the example chosen, T is 75 years for Area Sources 1 through 4, and 40 years for sources 5 and 6. There are 12 earthquakes greater than or equal to M = 3.5 for Line Source 1, 5 for Area Source 1, and 17 for Area Source 2.

The Gamma prior distribution on λ is characterized by two parameters λ' and ν', which are determined from subjective inputs. For this example, it is assumed that the values of λ' and ν' correspond to the T and N of the respective sources. The implication of this assumption is that the subjective information of the expert is similar to the available data; that is, there is as much confidence in his/her subjective input as in the data.

Based on the values of λ', ν', T, and N, the parameters λ'' and ν'' for the posterior distribution on λ can be computed for each source. In the absence of any subjective information, the analysis can be carried out with objective data alone; in the absence of any objective data, the analysis can be completed with only subjective information. Knowledge of λ'' and ν'' completely defines the probability function of the number of events based on λ.

Using the conditional Poisson distribution on λ and integrating over all λ's, the marginal Bayesian distribution of λ is obtained for each source. This distribution gives the probability of the number of events above a predetermined lower bound M. in the time period, T. The distribution on magnitude for these events is discussed in the next section.

7.1.2 Earthquake Magnitude Data - 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 represented by the binomial distribution. However, the probability of success, P_{M_i}, for each trial has been assumed to be uncertain and is treated as a random variable. A Bayesian treatment is used to obtain parameters of the Beta distribution used to describe the random variable P_{M_i}. The sample likelihood function of P_{M_i} 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 Mi (successes) recorded on the same source. The parameter r_{M_i} must be determined for each source and each M_i.

Using the conjugate prior distribution for the distribution (Beta type) on P_{M_i}, the parameters ξ''_{M_i} and η''_{M_i} are determined from subjective input. For this example, 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 a log-linear relationship (see Figure 24).

The prior η'_{M_i} represents the subjective knowledge about the number of events for a source above the fixed lower bound (M_i = 3.5) for each magnitude under consideration. As an example, consider the Line Source 1. From Table 2, the η'_{M_i} corresponding to this source is 16. The parameter ξ'_{M_i} represents the number of earthquakes of magnitude Mi. Again from Table 3, the cumulative sum of events are $N_C = 16$ for M = 3.50 and $N_c = 14$ for M = 3.75; thus, for Mi = 3.50, ξ_{M_i} is equal to 16 - 14 = 2. Because of the definition of the prior, M_i is constant for all M_i's within each source. 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. Having determined the parameters of the sample likelihood function, as well as those of the prior distribution, the posterior parameters η''_{M_i} and ξ''_{M_i} can be obtained by using the concept of conjugate distribution. The knowledge of η''_{M_i} and ξ''_{M_i} completely defines the probability distribution of the probability of success, p_{M_i}, of magnitude M_i on the source considered.

The marginal distribution of the number of successes, M_i's, is obtained by convolving the posterior distribution on P_{M_i} and the conditional generating process of r_{M_i}. Note, however, that this marginal distribution is still conditional on the number of events n. Combining the distribution of r_{M_i} for a given n, with the distribution on n, gives the marginal Bayesian distribution on r_{M_i}. This distribution is the number of events of each magnitude independent of the number of trials for a given source.

7.1.3 Fault Rupture-Length/Magnitude Relationship

The horizontal rupture lengths for various Richter magnitude levels (0.25 intervals) are based on the Patwardhan et al relationship (1975). Rupture width is taken as one-half the rupture length for a given magnitude.* The listing of the input data is in a file with card images.

*For the smaller earthquakes, where the change in rupture length between consecutive magnitudes is less than one integration step, a point source is used (0 rupture length). Even if they were not input as point ruptures, the program would reset them to zero length.

7.1.4 Attenuation

Probabilistic information on the various sources must be combined with information on the probabilistic attenuation relationship appropriate to the region of interest to obtain peak accelerations at a site. The SEISMIC.EXPOSURE program can accommodate several different relationships. For this example, the empirical relation derived from Idriss and others (1979) has been used from a data base of shallow earthquakes recorded on stiff soil. The relation is given by:

$$A = \frac{190.67e^{0.823M}}{(R + b_3)^{1.561}}$$ (See Data Entry XIII, Section 3.1)

with standard deviation $\ln_A = 0.568$, $b_3 = 0.864e^{0.463M}$, and A = PGA (peak acceleration, the ground-motion parameter of interest in this example). It will be further assumed in this example that the relation given above is valid for the magnitude range M = 3.5 to 8.00. It should be noted that in Data Entry XIII (Figure 16), the cards containing information on the attenuation coefficients (cards 2 and 3, respectively) are identical because the program requires at least two relationships. Only one was available for this example. If there were two different relations, the parameter DEPTH (in Data Entry XIV) would be used to separate the region of applicability of each; in this case, the parameter (-15.00 km) is irrelevant.

7.2 Program SEISMIC.EXPOSURE/Output

Figure 25 shows the job control statements required to execute the program SEISMIC.EXPOSURE using the three-source Sample Problem 1 inputs from a data file.

```
@RUN LINDA,,,S300,1000/1000                                    Job Control Language (JCL)
@SYM,F PRINTS,,PAZ
@SYM,D PRINTS
@BKI,A HAZSP1.
@HDG,N .M,66,4,2
@ASG,A NEWHAZ.
@ASG,A LCS*SP-SAOUT1.
@USE 26.,LCS*SP-SAOUT1. ———— Plotfile for 1st Parameter
@ASG,T 11o ———— Print file for first Parameter
@XQT NEWHAZ.NEWXQT
 SAMPLE PROBLEM USING TABLE GENERATION                          I - Heading
 NO  MARKOV INPUT USED
    3    0 ———— II - Plot Identification
  30.      0.       31.       2000000. ———— III - Map Projection Information
1.0      1.0     1.0       1.0     20.      1.0 ———— IV - Label Description for Plotting
30.0     30.0 ———— V - XORIG. YORG
    2    1   13    3    1    1  2  1  1    1   26    0    0   0    018 ———— VI - Problem Description
    1   17    1    1 ———— VII - Source/Magnitude Tables
 50.       .25       3*5 ———— VIII - Time Period and Magnitude
    1 30.686    31.854    -13.1
    2 30.343    32.024    -100
    3 30.657    32.704    -10.5
    4 31.070    32.5      -10.5
    5 32.8      31.878    -2.
    6 32..9     32.195    -2.                                   IX - Nodal Coordinates
    7 32.286    30.39     -5*
    8 32.286    31.573    -5.
    9 31.686    30.634    -It.
   10 31.686    31.207    -10.
   11 30.629    31.78     -10.
   12 31.029    31.268    -10.
   13 31.371    30.439    -10.
    1    4    3    2
    5    8    7    6                                             X - Elements
    6   10    9    7
AREA SOURCE 1                                                   13 ———— Card 1
    1    0    0    0    0 ———— Card 2                           XI - Area Source Properties
    1 ———— Card 3
250.     15.      2.4      2.6      1.5      2.1      0.8      1.6   Card 4
1.5      0.4      1.25     0.21     0.15     0.11     0.37
AREA SOURCE 2                                                   12
    2    0    0    0    1
    1    1
250.     38.5     4.5      2.5      4.5      5.       0.5      1.4
6.8      4.1      4.05     .2a      0.15     .15
LINE SOURCE 1                                                   13 ———— Card 1
    2   11    1    1 ———— Card 2                                XII - Line Source
150.     2e.      3.       2.5      1.5      4.       5.6      3.   Card 3
2.3      2.8      2*5      0.3      0.19     0.11     0.2
ACCELERATION PGA   20.     50.      1500.  ———— Card
190.67   (.923308  0.      S.561272  0.56A    0.———— Card 2     XIII - Attenuation Information
190.67   0.823308  0.      1.561272  0.563    0.———— Card 3
      55   3.0     -15.     0.8643   0.4626    5.0      5.0      0.1 ———— XIV - Attenuation Relations
0.       0.       0.       0.       0.       0.       0.       0.
0.       0.       0.       10.      26.      5.       80.      135.    XV - Horizontal Rupture Length
230.     400.
0.       0*       0.       0.       0.       0.       0.       0.
0.       0.       0.       5.0      15.      22.5     0.0      67.5    XVI - Down Dip Rupture Width
125.0    200.
GRID FOR SAMPLE PROBLEM (PROGRAM SEISMIC.HAZARD) WITHOUT MARKOV INPUT ———— Card 1
30.      30.      33.      30.      30.      33.      0. ———— Card 2        XVII - Grid Description
    4    0    0    0 ———— Card 3
@PRINTFILE 11 ———— Print file for 1st Parameter                 Job Control Language (JCL)
@BK2,N
@SYM,D PRINTS
```

Fig.25-SEISMIC. EXPOSURE Program Data Input for Sample Problem 1

Figure 26 shows the output for Sample Problem 1 as obtained from the line printer (i.e., logical unit equals 6). Comments have been included for clarity.

Figure 27 shows the output for Sample Problem 1 as saved on a print file (i.e., IWDT = 11; see Input Format, Card VI).

Figure 28 shows the output saved on disk to be used for plotting purposes (i.e., IWDT = 26; see Input Format, Card VI) and later, as part of the input data for program CONST.PROB.

7.3 Program CONST.PROB

The output printed from the program SEISMIC.EXPOSURE shown in Figure 28 becomes input to the program CONST.PROB. Since it is desired to compute the 5-percent probability of exceedance of maximum ground acceleration for a 50-year period of interest in Sample Problem 1, input data must be arranged as illustrated in Figure 29.

Output from CONST.PROB, as obtained on the line printer, is shown in Figure 30. The file in which the same data are stored, after program execution (See Figure 31), are part of the input data for the contour plotting done in the program PLOT.ISO.

7.4 Program PLOT.ISO

The computer output obtained from the program CONST.PROB is used as part of the input for program PLOT.ISO. Once the program is executed, a plot file is produced that can be viewed by CRT (with graphics capability) in order to check the results before obtaining standard CalComp plots. Typically, the CalComp plots are more expensive to run than the CRT plots because of system time and labor costs.

Fig. 26 – Output for Program SEISMIC. EXPOSURE (Sample Problem 1) as obtained on Line Printer

```
SAMFLEFROBLEM US ING1ABLE GENERATION
NO MARKOV I NFUT USED

PLOTTER SIZE                        3
PLOT FWT.ILXTION                    0
STANDARD LATITUDE 1                 30.0000
STANDARD LATITUDE 2                   .0000
STANDARD LONG 1 TUDE                31 .()()00
SCALING FACTOR                 2000000.
NUMBER OF AREA SOURCES              2
NUMBER OF LINE SOURCES              i
NUMBER OF NODES                     13
NUMBER OF E-I. EMENTS               3
NUMBER OF GRIDS                     1
NUMBER OF VARIABLES                 1
NUMBER OF ATT/VARIABLE              2
LINES PRINTED FER SITE              4
MAX N U . OF MAG                    18

S A U L RESULTS UN DISK (PLOTTING FORMAT)    4 0  VALUES FER SITE

TIME PERIOD    HAG INC    SMALLEST MAG
   50.00         ,25         3.50
```

NODAL COORDINATES (1 3 NODES)

NODAL INDEX	WCC INDEX	x COORD	Y COORD	Z (KM)	X (KM)	Y (KM)
1	1	30. 686	31 .854	-10.000	66.1307	205.394
2	2	30.343	32 024	–10.000	34.404	224.409
3	3	30.657	32.705	-10.100	64.340	299.939
4	4	31.070	32.500	-10.100	103.161	277.114
5	5	32.800	31.878	-2.000	267. 133	209.352
6	6	32.800	30.195	-2.000	270 . 052	22.573
7	7	32.286	30,390	-:>.000	220.:'74	43,546
8	8	32.286	31.573	-5.000	218.808	174.836
9	v	31.686	30.634	-10.000	162.3913	70.126
10	10	31.686	31.207	-10.000	162.019	133.717
11	11	30.6:'9	31.780	-10.000	.51.378	197.194
12	12	31.029	31.268	-10.000	99.335	140 294
13	13	31.371	30.439	-10.000	132.241	4LJ,350

Lest Two Columns: Xand Y Coordinates of each Node Have Been Transformed From From Degrees (Long.. Lat.) to Kilometers.

ELEMENTS DESCRIPTION (3 ELEMENTS)

INDEX	I	J	K	L	RENUMBERED I	J	K	L
1	1	4	3	2	1	4	3	2
2	5	8	7	6	5	8	7	6
3	8	10	9	7	8	10	9	7

Fig. 26 – Output for Program SEISMIC. EXPOSURE (Sample Problem 1) as obtained on Line Printer (continued)

```
AREA SOURCE     1
----------------

AREA SOURCE 1
NUMBER OF BANDS  1   BOUNDARY COND      .    .    5    0    ELEMENTS        THRU
NUMBER OF ELEMENTS IN EACH BAND STARTING WITH DEEPEST ON      1
TIME DATA BASE .............   250.00
NO OF OCC ..................    15.00
NO OF POISSON MAG. .........    13
SUM OF POISSON OCC. ........    14.990
DISTRIBUTION OF MAG.
       3.500      3.750      4.000      4.250      4.500      4.750      5.000      5.25       5.500      5.750
       2.400      2.600      1.500      2.100       .800      1.600      1.500       .400      1.250       .210

       6.000      6.250      6.500
        .150       .110       .300
THERE S NO SEMI-MARKOV INPUT FOR TH S SOURCE

AREA SOURCE     2
----------------

AREA SOURCE 2
NUMBER OF BANDS  2   BOUNDARY COND      .    .    .    1   ELEMENTS   2 THRU   5
NUMBER OF ELEMENTS IN EACH BAND STARTING WITH DEEPEST ONE     1    1
TIME DATA BASE .............   250.000
NO OF OCC ..................    38.50
NO OF POISSON MAG. .........    12
SUM OF POISSON OCC. ........    3 .930
DISTRIBUTION OF MAG.
       3.500      3.750      4.000      4.250      4.500      4.750      5.000      5.25       5.500      5.750
       4.500      2.500       .500      5.000      4.500      1.400      6.800       .10       4.150       .280
       6.000      6.250
        .150       .150
THERE IS NO SEMI-MARKOV  NPUT  OR TH S SOURCE

LINE SOURCE     1
----------------

LINE SOURCE 1
   2  SEGMENTS    BOUNDARY CONDITION              STARTING AT NODE         RENUMBERED
TIME DATA BASE .............   100.000
NO OF OCC ..................    28.000
NO OF POISSON MAG. .........    13
SUM OF POISSON OCC. ........    28.005
DISTRIBUTION OF MAG.
       3.500      3.750      4.000      4.250      4.500      4.750      5.000      5.25       5.500      5.750
       3.000      2.500      1.500      4.[illegible]      5.600      3.000      2.300      [illegible]      2.500       .3[illegible]
       6.050      6.250      6.500
        .190       .110       .200
THERE IS NO SEMI-MARKOV INPU  FOR TH S SOURCE

ATTENUATION RELATIONSHIPS

ACCELERAT ON PGA           IC=    20.000       MN=    50.000       MX=  1500.000
        B1          B2          B3          B4     LN SIG        MG MX
     190.670       .823        .400      1.561       .568        .000
     190.600       .823        .000      1.561       .568        .000

C1                .364
C2                .463
DEPTH          -15.000
```

Fig. 26 – Output for Program SEISMIC. EXPOSURE (Sample Problem 1) as obtained on Line Printer (continued)

```
ATTENUATION RELATIONSHIPS

ACCELERATION PGA         IC=   20.00       MN=   50.000       MX=  1500.000
      B1            B2          B3          B4       LN SIG       MG MX
   190.670         .823        .000       1.561       .568        .000
   190.670         .823        .000       1.561       .568        .000

C1                 .864
C2                 .463
DEPTH           -15.000

LOG-NORMAL DISTRIBUTION ON ATTENUATION
NO OF SIG ON EACHSIDE OF MEAN     3.0
NO OF INCREMENTS IN DIST           8[illegible]

INTG. STEP VERT. (KM)           5.000
INTG. STEP HOR.  (KM)           5.000
EPSILON          (KM)            .10.

SOURCE/MAGNITUDE CONTRIBUTION TABLE INFORMATION
-------------------- -------- ------------ --------

INPUT SPECIFIES TABLES ARE 10 BE GENERATED FOR EVERY   1 INCREMENTS UP TO INCREMENT  17 FOR THESE PARAMETERS -
   1


PARAMETER TABLE SIZE (SUM OF MAGNITUDES ACROSS ALL SOURCES) = 36

PARAMETER      MINIMUM     MAXIMUM     INCREMENT   FIRST TABLE   LAST TABLE   FIRST LEVEL   LAST LEVEL    ADDRESS
----------  ----------- ----------- ----------- ------------- ------------ ------------- ------------ ----------
    1          50.000    1500.000      20.000       60.000      320.000          9             17           [illegible]

TABLE SPACE AVAILABLE -     10800
TABLE SPACE USED      -       532

HORIZONTAL RUPTURE LENGTHS (KM)
    3.500      3.750      4.000      4.250      4.500      4.750      5.000      5.250      5.500      5.750
     .000       .000       .000       .000       .000       .000       .000       .000       .000       .000
    6.000      6.250      6.500      6.750      7.000      7.250      7.500      7.75
     .000     18.000     26.000     45.000     80.000    135.000    230.000    40[illegible].000

DOWN DIP RUPTURE LENGTHS (KM)
    3.500      3.750      4.000      4.250      4.500      4.750      5.000      5.250      5.500      5.750
     .000       .000       .000       .000       .000       .000       .000       .000       .[illegible]       .[illegible]
    6.000      6.250      6.500      6.750      7.000      7.250      7.500      7.75
     .000      9.000     13.000     22.500     40.000     67.500    125.000    2[illegible]0.000

THE CONSTANT C = C1 * EXP(C2*M) IN ATTENUATION EQUATION
   4.3635     4.8984     5.4990     6.1732     6.9300     7.7797     8.7335     9.8042     11.006     12.356
   13.871     15.571     17.480     19.623     22.029     24.730     27.762     31.166

PARAMETER 1  - ACCELERATION PGA

ATTENUATION COEFFICIENT B1 * EXP(B2 * M)
   8.1321     8.3379     8.5438     8.7496     8.9554     9.1613     9.3671     9.5729     9.7787     9.9846
   10.190     10.396     10.602     10.808     11.014     11.220     11.425     11.631

ATTENUATION COEFFICIENT B1 . EXP(B2 . M)
   8.1321     8.3379     8.5438     8.7496     8.9554     9.1613     9.3671     9.5729     9.7787     9.9846
   10.190     10.396     10.602     10.808     11.014     11.220     11.425     11.631
```

Fig, 26 – Output for Program SEISMIC. EXPOSURE (Sample Problem 1) as obtained on Line Printer (continued)

PROBABILITY OF ZERO OCCURANCE PER INCREMENT

MAG	AREA SOURCE 1	AREA SOURCE 2	LINF SOURCE 1
5*5U	.996456	.998296	.Y574Y7
3.75	.996166	.999042	.904317
4.00	.997771	.998236	.978267
4.25	.996893	.998098	.944153
4.50	.q9ti 806	.598286	.923593
4.75	.997625	.9994b2	.'757497
5.00	.')97771	.997425	.YL! 7.74
5.25	9999401	.998436	.961213
5.50	.998140	.99 H455	.964317
5*75	.599685	.999892	.995573
6.0C	.999775	.999942	.997191
6.25	.9998 .35	.999942	.998372
6.5G	.599446	.cc9cclc	.997144

Fig. 27 – Output for Program SEISMIC. EXPOSURE as Saved on Printfile for Each Ground Motion Parameter

```
@PRINTFILE

****** P R O B A B I L I T Y   O F   A T   L E A S T   O N E   E X C E E D E N C E   I N   5 .   Y E A R S  ******

 SAMPLE PROBLEM USING TABLE GENERATION
 NO MARKOV INPUT USED
GRID FOR SAMPLE PROBLEM (PROGRAM SEISMIC.HAZARD)WITHOUT MARKOV INPU

                          A C C E L E R A T I O N   P G A

INC =      20.000
MIN =      50.000
MAX =    1500.000

SITE COORDINATES X,Y,Z           30.000     30.000      .000       .000       .000

    .00000     20.00000    40.00000    60.00000    80.00000   100.00000   120.00000   140.00000   160.00000   180.00000
   1.00000       .38989      .30862      .00101      .00014      .00000      .00000      .00000      .00000      .00000
      .00        531.32     5773.64    49265.17        .00         .00         .00         .00         .00         .00

 200.00000    220.00000   240.00000   260.00000   280.00000   300.00000   320.00000   340.00000   360.00000   380.00000
    .00000       .00000      .00000      .00000      .00000      .00000      .00000      .00000      .00000      .00000
      .00          .00         .00         .00         .00         .00         .00         .00         .00         .00

 400.00000    420.00000   440.00000   460.00000   480.00000   500.00000   520.00000   540.00000   560.00000   580.00000
    .00000       .00000      .00000      .00000      .00000      .00000      .00000      .00000      .00000      .00000
      .00          .00         .00         .00         .00         .00         .00         .00         .00         .00

 600.00000    620.00000   640.00000   660.00000   680.00000   700.00000   720.00000   740.00000   760.00000   780.00000
    .00000       .00000      .00000      .00000      .00000      .00000      .00000      .00000      .00000      .00000
      .00          .00         .00         .00         .00         .00         .00         .00         .00         .00
```

First Three Values are the Site Coordinates X, Y, Z in Degrees (Long. Lat.) and Depth (Kilometers). The Last Two Values are the Site Coordinates X, Y in Kilometers

PGA Levels in cm/sec^2

Values of Complementary Distribution Function (1–CDF)

Return Period in Years

```
         PARAMETER      ACCELERAT ON PGA      =      60.00      MAGNITUDE/SOURCE PERCENTAGE CONTRIBUTION TABLE      PART 1
```

MAG	AREA SOURCE 1	AREA SOURCE 2	LINE SOURCE 1	ROWSUMS
3.50	.0000	.0000	.0000	.0000
3.75	.0000	.0000	.0000	.0000
4.00	.0000	.0000	.0000	.0000
4.25	.0000	.0000	.0000	.0000
4.50	.0000	.0000	.0000	.0000
4.75	.0000	.0000	.0000	.0000
5.00	.0000	.0000	.0000	.0000
5.25	.0000	.0000	.0000	.0000
5.50	.0000	.0000	.0000	.0000
5.75	.0000	.0000	.0000	.0000
6.00	.0000	.0000	7.4390	7.4390
6.25	.0000	.0000	15.8923	15.8923
6.50	.0000	.0000	76.6687	76.6687
SUMS	.0000	.0000	100.0000	.10149-002

Fig. 27- Output for Program SEISMIC. EXPOSURE as Saved on Printfile for Each Ground Motion Parameter (continued)

PARAMETER 1 ACCELERATION PGA= 80.0 MAGNITUDE/SOURCE PERCENTAGE CONTRIBUTION TABLE PART 1

MAG	ARCA SOURCE 1	AREA SOURCE 2	LINE SOURCE 1	ROWSUMS
3.50	.0000	.0000	.0 [,011	.0000
3.75	.0000	.0000	.0000	.0000
4.00	.0000	.0000	.0000	.0000
4.25	.0000	.0000	.0000	.0000
4.50	.0000	.0000	.0000	.0000
4.75	.0000	.0000	.0000	.0000
5.00	.0000	.0000	.0000	.0000
5.25	.0000	.0000	L,.3(,	.0000
5.50	.0000	.0000	.0000	.0000
5.7s	.0000	.0000	.0000	.0000
6.00	.0000	.0000	.0000	.0000
6.25	.0000	.0000	5.8024	5.8024
6.50	.0000	.0000	94.1976	94.1976
SUMS	.0000	.0000	100.0000	136 U5-0C3

PARAMETER 1 - ACCELERATION PGA >= 100.00
*** SOURCE/MAGNITUDE CONTRIBUTION TABLES ARE EMPTY . . .

PARAMETER 1 ACCELERATION PGA SUMMARY MAGNITUDE/SOURCE CONTRIBUTION TABLE PART 1

VALUE	AREA SOWICE 1	ARCA SOURCE 2	LINE SOURCE 1	ROWSUMS
60.0	.00000	.00000	.101 QY-JJ2	.1 OI49-LL2
80.o	.00000	.00000	.13603-0C3	.13603-0C3
100.0	OOOGO	I) Goo J	.00000	.00000
120.0	OOOGO	.00000	.00000	.00000
140.0	.00300	0000J	.00000	.00000
16000	.00000	.00000	.00000	.00000
180.0	OOCOO	.00000	.00000	.0 0030
200.0	.00000	.00000	.00000	.00000
22000	.00000	.00000	.00000	.00000
240.0	.00000	.00000	.00000	ilo Lilu
26.0.0	.00000	.00000	.00000	.00000
28000	00000	.00000	.00000	.00000
300.0	.00000	.00000	.00000	.00000
320.0	.00000	.00 3011	.00000	.00000

NOTE:
Output for Remaining 15 Sites is not Shown Since the Form is the Same

Fig. 28- Output from Program SEISMIC. EXPOSURE (Sample Problem 1)
as saved on Disk for Plotting Purposes

```
@PRINTF ILE LCS*SF-SAOUT1.
  1          0
  30 .02       ,000    31.000  2000000.       .000
   1.000     1.000     1.000     1.000     20.000      1.000       .000
SAMPLE PROBLEM USING TABLE GENERATION
NO MARKOV INPUT USED
ACCELERAT 10N PGA          20.000     50 .000   1500.000     50.000
GRID FOR SAMPLE PROBLEM ( PROGRAM SE I SMI C HAZARD)WITHOUT MARKOV INPUT
  30.000    3 30.000     33.000     30.000     30.000     33.000
   4      " 4  0  0
        40
 1.00000  .08989  .00862  .00101  .00014  .00000  .00000  .00000  .00000  .00000
  .00000  .00000  .00000  .00000  .00000  .00000  300000  .00000  .00000  ,00000
 ,00000  ,00000  .00000  .00000  ,00000  .00000  .00000  .00000  .00000  .00000
  .00000  .00000  .00000  .00000  .00000  .00000  ,00000  .00000  ,00000  ,00000
 1.00000  .72507  .18299  ,03940  .01121  .00381  .00133  .00054  .00023  .00011
  . 0000s  .00002  .00001  .00000  .00000  ,00000  .00000  .00000  .00000  .00000
  .00000  ,00000  .00000  , 00000  ,00000  .00000  .00000  .00000  .00000  .00000
 00000  .00000  00000  .00000  .00000  .00000  .00000  .00000  .00000  ,00000
 1>00000  .77721  .18429  .03492  .00877  .00260  .00089  .00034  .00012  .00005
  .00002  .00001  .00000  .00000  ,00000  ,00000  ,00000  .00000  .00000  .00000
  .00000  00000  . 00000  ,00000  .00000  .00000  .00000  , 00000  .00000  .00000
  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000
 1.00000  .72817  . 22522  .06148  .02132  ,00853  .00367  .00176  .00080  ,00043
  .00022  .00013  .00007  .00004  .00003  ,00002  .00001  .00001  . 00000  .00000
  .00000  .00000  .00000  ,00000  ,00000  .00000  .00000  .00000  .00000  ,00000
  .00000  ,00000  .00000  .00000  .00000  .00000  .00000  .00000  ,00000  .00000
 1 . 00000  .66172  11014  .01752  .00347  . 00099  . 00028  .00008  .00000  ,00000
  .00000  .00000  :00000  . 00000  ,00000  .00000  . 00000  .00000  .00000  .00000
  .00000  .00000  .00000  .00000  ,00000  .00000  .00000  .00000  .00000  ,00000
  .00000  .00000  .00000  . 00000  .00000  .00000  ,00000  .00000  ,00000  .00000
 1 .00000  .99991  .98941  .90603  . 748s7  .57188  .41207  .29468  19729  13976
  . 0%91  . 07282  .04692  . 034s5  .02942  802078  .01479  .01200  :00838  :00680
  .00452  .00375  , 00291  .00227  .00187  . 00153  .00106  . 00082  . 00068  ,00045
  .00032  .00029  ,00024  .00020  .00014  .00013  .00012  .00009  .00006  .00006
 1.00000  ,99666  ,70648  . 27785  11048  .04753  .02158  .01089  .00521  .00287
  .00151  ,00090  ,00049  .00031  :00024  .00015  .00008  .00007  .00004  . 00003
  .00001  ,00001  .00001  .00000  .00000  .00000  . 00000  .00000  .00000  .00000
  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000
 1.00000  .99133  . 75000  ,37763  , 18702  .09649  .05112  .02912  .01587  , 0097s
  .00582  .00405  , 00231  .00153  .00126  .00084  .00054  .00044  ,00027  .00021
  .00014  .00010  .00008  .00007  ,00005  .00004  .00003  .00003  .00002  .00001
  .00001  .00001  .00001  .00000  .00000  .00000  .00000  ,00000  .00000  .00000
 1.00000  ,80902  , 25073  . 06292  , 02041  .00772  .00319  .00148  .00065  ,00033
  .00016  .00010  . 00004  .00002  .00002  ,00001  .00001  .00000  .00000  .00000
  .00000  .00000  .00000  .00000  .00000  ,00000  .00000  ,00000  ,00000  .00000
  .00000  .00000  .00000  ,00000  .00000  . 00000  .00000  .00000  ,00000  .00000
 1.00000  .99257  .73067  .33544  . 15265  .07380  .03713  .02036  .01060  ,00625
  .00360  . 00245  00136  ,00091  .00073  . 00046  , 00029  .00022  .00014  .00010
  .00006  .00004  .00004  .00003  .00002  .00001  ,00001  .00000  .00000  .00000
  .00000  .00000  00000  .00000  .00000  .00000  .00000  .00000  ,00000  .00000
 1 . 00000  -72239  .16268  .03004  .00739  .00?18  .00046  .00027  .00010  .00005
  .00002  .00001  .00000  .00000  .00000  .00000  .00000  . 00000  ,00000  .00000
  .00000  ,00000  .00000  .00000  .00000  800000  .00000  .00000  .00000  .00000
  .00000  ,00000  .00000  .00000  ,00000  .00000  .00000  .00000  .00000  .00000
 1.00000  .75.518  .26965  .00493  .03305  .01456  .00602  .00353  .00174  .00098
 000s4  . 00035  .00018  .00012  .00009  .00005  .00003  .00002  .00002  . 00001
  .00001  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000
  .00000  ,00000  .00000  . 00000  ,00000  .00000  .00000  .00000  .00000  .00000
 1.00000  .22113  , 02837  .00444  .00094  .00024  .00007  .00002  .00000  .00000
  .00000  .00000  .00000  , 00000  ,00000  ,00000  .00000  .00000  .00000  .00000
  .00000  ,00000  .00000  .00000  ,00000  . 00000  ,00000  .00000  .00000  .00000
 ,00000  ,00000  ,00000  .00000  ,00000  .00000  .00000  .00000  .00000  .00000
 1.00000  .47473  13144  .03918  .01518  .00673  .00317  .00164  .00080  . 00045
  ,00024  .00015  : 00008  .00005  .00004  ,00002  .00001  .00001  800000  .00000
  .00000  .00000  .00000  ,00000  .00000  .00000  . 00000  .00000  .00000  .00000
  .00000  .00000  .00000  .00000  .00000  ,00000  .00000  .00000  .00000  .00000
 1.00000  .04497  .00351  .00043  ,00004  . 00001  .00000  .00000  .00000  .00000
  .00000  .00000  .00000  .00000  .00000  ,00000  .00000  ,00000  .00000  .00000
  .00000  .00000  .00000  .00000  . 00000  .00000  .00000  .00000  . 00000  .00000
  .00000  .00000  , 00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000
 1 .00000  .00466  .00037  .00000  .00001  . 00000  . 00000  .00000  . 00000  .00000
  .00000  ,00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000  .00000
  .00000  ,00000  .00000  .00000  .00000  .00000  .00000  ,00000  .00000  .00000
  .00000  .00000  .00000  .00000  .00000  .00000  . 00000  .00000  .00000  .00000
@BK2 PAZ
```

- XI-{I-CDF)Cards

Fig. 29- Input to Program CONST. PROB

1 1 0 05 — I Input from Unit 5

Input as read from Plotfile created by Program SEISMIC. *EXPOSURE.*
Always read in, from Unit 9

1 3 0 — II
30.000 .000 31.000 2000000. .000 — III
1.000 1.000 1.000 1.000 20.000 1.000 .000 — IV
SAMPLE PROBLEM USING TABLE GENERATION
NO MARKOV INPUT USED — V
ACCELERATION PGA 20.000 50.000 1500.000 50.000 — VI
ORID FOR SAMPLE PROBLEM (PROGRAM SEISMIC.HAZARD) WITHOUT MARKOV INPUT — VII
30.000 30.000 33.000 30.000 30.000 33.000 — VIII
4 4 0 0 — IX
40 — X

1.00000	.08989	.00862	.00101	,00014	00	.00000	.00000	,00000	.00000
,00000	.00000	,00000	.00000	,00000	.00000	,00000	.00000	.00000	.00000
.00000	.00000	.00000	.00000	,00000	.00000	.00000	,00000	.00000	.00000
,00000	.00000	.00000	.00000	.00000	.00000	,00000	.00000	.00000	. 00000
1.00000	72507	.18299	.03940	.01121	,00301	.00133	.00054	.00023	.00011
, 0000s	:06002	. 00001	.00000	, 00000	. 00000	,00000	.00000	.00000	.00000
.00000	.00000	.00000	.00000	,00000	.00000	.00000	. 00000	.00000	.00000
.00000	.00000	.00000	.00000	.00000	.00000	,00000	.00000	.00000	.00000
1.00000	.77-721	18429	,03492	.00877	, 00260	.00089	.00034	.00012	.00005
,00002	.00001	:00000	.00000	. 00000	,00000	.00000	. #000	,00000	.00000
.00000	.00000	,00000	.00000	# 00000	.00000	,00000	,00000	,00000	.00000
,00000	.00000	,00000	.00000	.00000	.00000	, 00000	,00000	,00000	.00000
1.00000	.72817	,22522	.06148	.02132	,00853	,00367	.00176	. 00080	.00043
00022	.00013	.00007	. 00004	.00003	.00002	.00001	800001	.00000	.00000
.00000	.00000	.00000	.00000	,00000	,00000	,00000	. 00000	.00000	.00000
,00000	800000	. 00000	.00000	.00000	.00000	.00000	.00000	,00000	.00000
1. 00000	.66172	.11014	.01752	,00347	.00099	.00029	.00008	,00000	.00000
,00000	.00000	.00000	.00000	. 00000	.00000	.00000	,00000	,00000	.00000
,00000	.00000	,00000	. 00000	,00000	.00000	.00000	.00000	.00000	,00000
,00000	.00000	.00000	. 00000	.00000	.00000	,00000	.00000	.00000	.00000
1,00000	. 99991	,98941	.90603	, 74857	.57188	.41207	.29468	. 19729	13976
09s91	07282	,04692	. 0345s	.02942	, 02078	.01479	.01200	. 00S38	:00680
.00452	.00375	. 002?1	.00227	00187	.00153	.00106	. 00082	. 00068	.00045
,00932	,00029	,00026	,00020	.00014	.00013	.00012	,00009	.00006	.00006
1 . 00000	.99666	, ?0640	27785	1 1048	.04753	. 02158	.01089	.00521	. 00287
.00151	.00098	,00049	.00031	:00024	.00015	.00008	,00007	.00004	.00003
.00001	,00001	,00001	.00000	.00000	.00000	. 00000	.00000	.00000	. 00000
,00000	.00000	.00000	.00000	,00000	.00000	.00000	.00000	.00000	,00000
1.00000	.99133	.75000	.37763	.18702	.09649	.05112	.02912	.01587	. 0097s
.00502	.00405	.00231	.00153	.00126	.00084	. 00054	.00044	· 00027	.00021
.00014	,00010	,00000	, 00007	.00005	.00004	,00003	. 00003	,00002	.00001
,00001	.00001	.00001	.00000	.00000	.00000	. 00000	.00000	.00000	.00000
1.00000	.80902	,25073	.06292	.02041	.00772	.00319	.00148	. 00065	.00033
.00016	.00010	.00004	.00002	.00002	.00001	.00001	800000	.00000	.00000
,00000	.00000	.00000	.00000	.00000	.00000	.00000	,00000	.00000	. 00000
.00000	.00000	.00000	.00000	. 00000	.00000	.00000	.00000	. 00000	.00000
1.00000	.99257	.73067	.33544	.15265	.07380	.03713	.02036	.01060	.00625
.00360	, 00245	.001s6	.00091	. 00073	.00046	. #029	,00022	.00014	,00010
.00004	.00004	.00004	.00003	.00002	.00001	,00001	.00000	.00000	. 00000
.00000	.00000	.00000	00000	.00000	00000	. 00000	,00000	.00000	.00000
1.00000	.72239	16268	.03004	.00739	.00218	.00066	.00027	.00010	.00005
.00002	.00001	:00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
.00000	. 00000	.00000	.00000	00000	.00000	.00000	.00000	.00000	. 00000
.00000	.00000	.00000	.00000	.00000	,00000	,00000	.00000	.00000	.00000
1.00000	.75618	.2′5965	.00493	.03305	.01456	.00682	.00353	.00174	00098
. 000s4	,00035	.00018	.00012	.00009	0000s	.00003	.00002	. 00002	,00001
.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
00000	.00000	.00000	.00000	.00000	. 00000	,00000	.00000	.00000	.00000
1.00000	.22113	. 02837	.00444	.00094	.00024	.00007	.00002	.00000	.00000
.00000	,00000	.00000	.00000	,00000	.00000	.00000	.00000	.00000	.00000
.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	,00000	.00000
.00000	.00000	>00000	.00000	,00000	.00000	.00000	.00000	.00000	.00000
1.00000	.47473	. 13144	.03918	.01518	.00673	. 00317	.00164	,00080	. 0004s
.00024	.00015	. 00008	.00005	.00004	.00002	.00001	.00001	.00000	. 00000
.00000	.00000	,00000	.00000	.00000	,00000	.00000	.00000	.00000	.00000
.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
1.00000	,04497	.00351	.00043	,00004	.00001	.00000	.00000	.00000	. 00000
.00000	.00000	.00000	,00000	.00000	.00000	800000	.00000	.00000	.00000
.00000	.00000	.00000	.00000	,00000	.00000	.00000	.00000	.00000	,00000
.00000	.00000	.00000	,00000	.00000	.00000	000000	.00000	.00000	.00000
1.00000	.00466	.00037	.00008	.00001	.00000	.00000	.00000	.00000	.00000
.00000	.00000	.00000	,00000	.00000	.00000	.00000	,00000	.00000	.00000
.00000	.00000	[illegible]	.00000	.00000	.00000	.00000	,00000	[illegible]	[illegible]
.00000	.00000		.00000			.		.00000	

XI-(I-CDF)Cards

Fig. 3o – Output for Program CONST. PROB (Sample Problem 1
As Obtained on Line Printer

```
STANDARD LATITUDE 1          30.0000
STANDARD LATITUDE 2            .0000
STANDARD LONGITUDE           31.0000
SCALE               1   TO  2000000.0
X MARK  EVERY                1.0000
Y MARK  EVERY                1.0000
X LABEL EVERY                1.0000
Y LABEL EVERY                1.0000
CONTOUR LINE  EVERY          20.0000
CONTOUR LABEL EVERY             1.0  LINES
CROSSES INSIDE? 0=NO             .0
NUMBER OF GRIDS                  1
NUMBER OF PROB LEVELS            1
PROBABILITY LEVELS             .050
 SAMPLE PROBLEM USING TABLE GENERATION
 NO MARKOV INPUT USED                                                                   NXMX =          4   NYMX =          4
   XXOR =      30.000   YYOR =      30.000   XXRT =      33.000   YYRT =      30.000   XXUP =     30.000   YYUP =     33.000
ACCELERATION PGA              PROBABILITY OF EXCEEDENCE        .050
    29.817    58.524    57.981    65.717
    52.986   237.622    99.215   121.018
    66.079   112.981    56.990    73.466
    37.756    57.654    19.895    19.089
```

Fig. 31 – Output for Program CONST. PROB (Sample Problem 1) –
As Saved on Disk for Plotting Purposes – Always Unit 10

1 3	0 SAMPLE PROBLEM USING TABLE GENERATION				
30.00000	.00000	31.00000	2000000.	.00000	
	4 0	0			
:0.00:	30.000	33.000	30.000	30,000	33,000
1.000	1.000	1.000	1.000	20.000	1.000
PROB OF NON-EXCEEDENCE		.950			
29.817	50.324	57.901	65.717		
52.986	237.622	99.21s	121.0113		
66.079	112.981	56.990	"73.466		
37.7s6	57,654	19.895	19.089		

Figure 32 shows the listing of the input data deck (data file) for the program PLOT.ISO. Each Data Entry, as described in Section 3.1, is noted on the figure by the corresponding item number.

Figure 33 shows the output as obtained on the line printer from execution of PLOT.ISO. The output can be checked for proper program execution and to determine whether these were calls to "FOURPT." See Section 6.1 and Figure 22 for an explanation of what to do if there are calls to "FOURPT" during execution of the contouring routine in PLOT.ISO.

Figure 34 shows the contoured maximum ground acceleration for a 5-percent level of exceedance (or 95-percent level of non-exceedance) over a 50-year future time period for the region of interest (Figure 9) , Sample Problem 1.

The seismic exposure map in Figure 34 was obtained without using semi-Markov inputs for large and great earthquakes. A second sample problem that handles a subduction seismicity environment where large and great earthquakes are considered is discussed in the next section.

7.5 Program MARKOV--Sample Problem 2

This sample problem illustrates the capability of the SEISMIC.EXPOSURE program to handle subduction zone seismicity (seismic gaps). Only the essential inputs that differ from the first sample problem will be discussed here. The problem consists of determining the seismic exposure at several sites from which a seismic exposure map is generated for maximum acceleration with a 5-percent probability of exceedance in a 50-year future time period.

Fig. 32 – Input for Program PLOT·ISO

Input From Unit 5

```
9 ————————————————————————————————— Read Input Unit
```

Input From Plotfile Created by Program CONST. PROB

```
    1    30      0 SAMPLE PROBLEM USING TABLE GENERATION   ——— I
 30.000000      .00000  31.00000  2000000.     .00100 ——— II
    1     4      4     0     0 ——————————————————————————— III
   30.000      30.000    33.000     30.000     30.000     33.000 — IV
    1.000       1.000     1.000      1.000     20.000      1.000 — V
PROB OF NON-EXCEEDENCE          .950 ————————————————————— VI
   29.817      58.524    57.961     65.717 ┐
   52.986     237.622    99.215    121.013 │
   66.079     112.981    56.990     73.[illegible] ├──────────── VIII
   37.756      57.654    19.695     19.989 ┘
```

Fig. 33 – Output from Program PLOT . ISO as Obtained on Line Printer

```
SAMPLE PROBLEM USING TABLE GENERATION                                        1 DIFFERENT FRAMES
PLOTTER SIZE = 30 INCHES
     LAMBERT CONIC CONFORMAL PROJECTION WITH 1 STANDARD PARALLEL
PLOT TYPE
STANDARD LATITUDE 1          30.000:
STANDARD LATITUDE 2           ,0000
STANDARD LONGITUDE           31.0000
SCALE               1 TO 2000000.0
NUMBER OF PLOTS                    1
NO OF POINTS IN X DIR              4
NO OF POINTS OF Y DIR              4
FLOT FRAME? O=NO                   O
INT FROM ACC? O=NO
X MARK EVERY                  1.000:
Y MARK EVERY                  1 0000
X LABEL EVERY                 1.0000
Y LABEL EVERY                 1.0000
CONTOUR LINE EVERY           20.0000
CONTOUR LABEL EVERY             1.O LINES
CROSSES INSIDE O=NO             .O
GRID COORDINATES X        30.000    33.000    33.000    30 000
                 Y        30. 000   30.000    33.000    33.000


PLOT TYPE        1    NUMBER       1

DATA MATRIXFIRST LINE CORRESPOND TO SOUTH, LAST TO NORTH

PROB OF NON-EXCEEDENCE          .950                                  O MODIFIED CALLS IN FOURPT
   29.817     58,524    57.981    65,717
   52 986    237.622    99.215   121 .01s
   66.079    112.961    56.990    73.466
   37.756     57,654    19. S95   19.089
LOU VALUE                   19.0s9
HIGH VALUE                 237, 622
NUMBER OF COUNTOURS              11

CONTOUR        1   LEVEL      20 000
CURVE     1 STARTS AT     1 ENDS AT     3
DXX**2 =  .00001 DYY**2=  .00001 DSMN =  00008

CONTOUR        2   LEVEL      40.000
CURVE     1 STARTS AT     1 ENDS AT     2
CURVE     2 STARTS AT     3 ENDS AT     4
CURVE     3 STARTS AT     5 ENDS AT     7

CONTOUR        3   LEVEL      60.000
CURVE     1 STARTS AT     1 ENDS AT     5
CURVE     2 STARTS AT     6 ENDS AT    11

CONTOUR        4   LEVEL      80.000
CURVE     1 STARTS AT     1 ENDS AT     9

CONTOUR        5   LEVEL     100.000
CURVE     1 STARTS AT     1 ENDS AT     3
CURVE     2 STARTS AT     4 ENDS AT     9

CONTOUR        6   LEVEL     120.000
CURVE     1 STARTS AT     1 ENDS AT     3
CURVE     2 STARTS AT     4 ENDS AT     7

CONTOUR        7   LEVEL     140.000
CURVE     1 STARTS AT     1 ENDS AT     4

CONTOUR        8   LEVEL     160.000
CURVE     1 STARTS AT     1 ENDS AT     4

CONTOUR        9   LEVEL     180 .000
CURVE     1 STARTS AT     1 ENDS AT     4

CONTOUR       10   LEVEL     200.000
CURVE     1 STARTS AT     1 ENDS AT     4

CONTOUR       11   LEVEL     220.000
CURVE     1 STARTS AT     1 ENDS AT     4
```

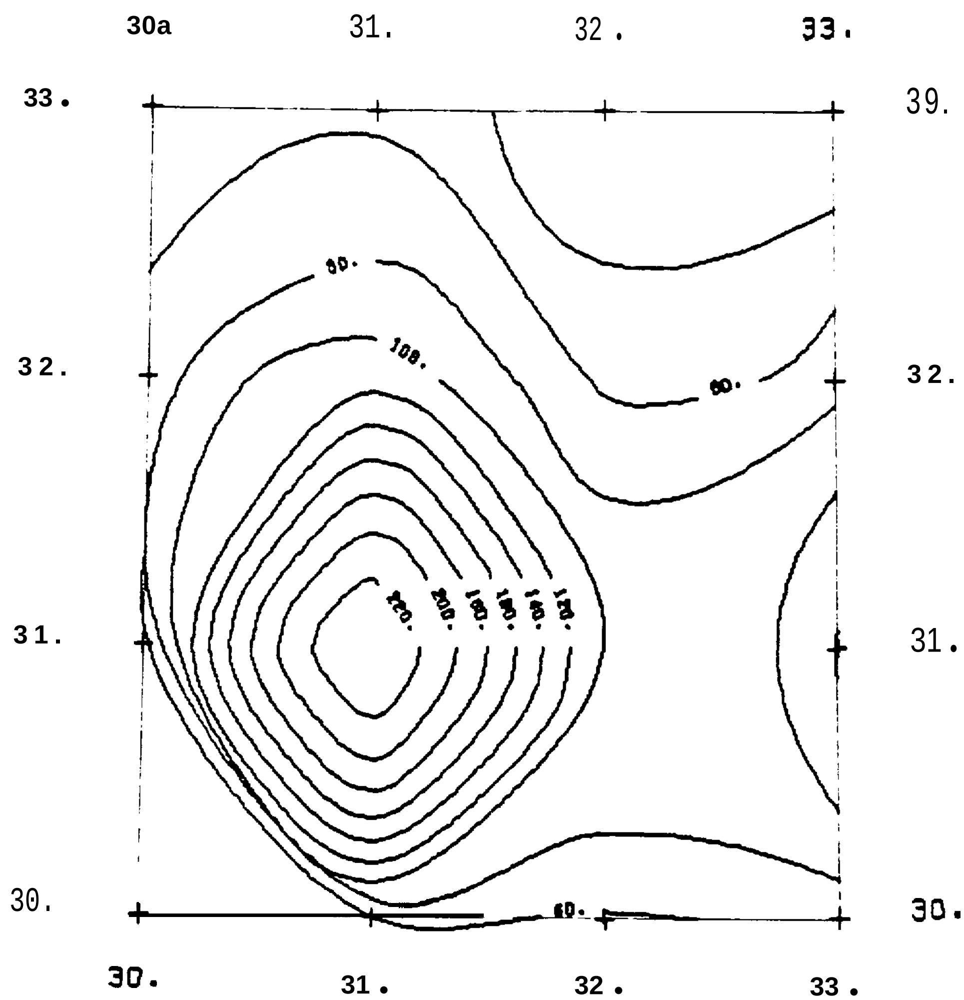


Fig 34 – Seismic Exposure Map for PGA, Probability of Exceedance of 5 Percent and Time Period of 50 Years

Since results from the semi -Markov model are desired, inputs must be obtained from the program MARKOV. These inputs consist of the probabilities of occurrence and the magnitude distribution of the number of earthquakes contributed by large earthquakes from the subduction zone ("seismic gaps").

Five sources are considered in a region of interest, as shown in Figure 35. Three of the area sources have recurrence input from the MARKOV program.

7.5.1 Seismicity Data

For earthquakes of M_S <u>¼</u> 7.6 on the Benioff zone sources, seismicity has been proportioned on the basis of area proportions of the seismicity from recurrence curves for the shallow and intermediate sections of the subduction. Procedures used are those described in Sections 7.1 for Sample Problem 1. The recurrences for random and area sources are handled in a similar manner.

Recurrences for earthquakes Of Ms ½ 7.6 and seismic gaps are obtained from inputs to the SEISMIC.EXPOSURE program from the program MARKOV. MARKOV must be executed prior to the execution of SEISMIC.EXPOSURE. Because of the seismic gaps in this tectonic environment, subjective data from judgments made by experts are combined with the historical data in order to provide the proper inputs to the program MARKOV. Details of procedures to synthesize subjective information from geology and historical earthquake data with assessments on the holding times and magnitudes of large earthquakes in seismic gaps are discussed in detail in Appendices A and D.

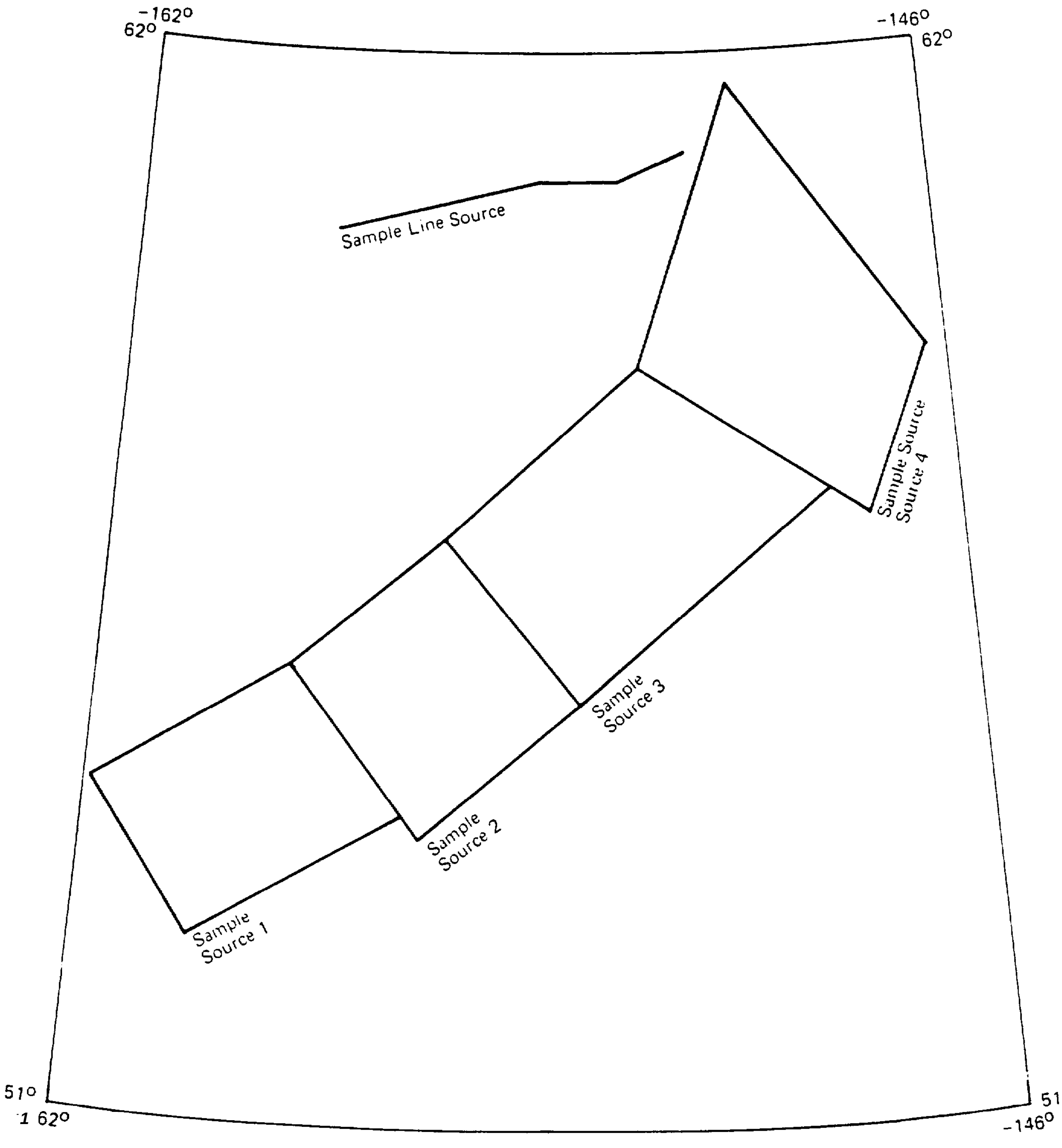


Fig. 35 -SUBDUCTION ZONE TECTONIC ENVIRONMENT— SAMPLE PROBLEM 2

7.5.2 Input Data to MARKOV

Figure 36 shows the input data to the program MARKOV. Data set entry comments correspond to discussions in Section 4.1. In this sample problem, the period of interest is 40 years, with the cutoff magnitude being 7.8 Ms for non-semi-Markov earthquake recurrence inputs. The prior distributions are M_1, M2 and M3, and T_{11}, T_{12} . . . . ..Tij's are hypothetical. They may be developed for a given problem using the procedures discussed in Appendix D. Figure 37 shows the output as obtained on the line printer for Sample Problem 2. Descriptions are provided of the input parameters and statistics on the distributions used on the holding time and magnitude (state) transitions. The essential results from the output are shown in Figure 38: the probabilities of earthquakes occurring with the various magnitude states.

7.S.3 Input Data to SEISMIC.EXPOSURE

The input data to the program SEISMIC.EXPOSURE are shown in Figure 39. The necessary source geometries, map projection, grid information, recurrence information, and attenuation information are also shown in the figure, and the essential differences between the types of input data and the first sample problem are noted. Input data resulting from the semi-Markov simulation in the program MARKOV shown in Figure 38 appear in the disk files labeled 17 (INDATA). In this example, the input semi-Markov results for the SEISMIC.EXPOSURE program could have been written to three separate files (i.e., 17, 18, and 19) by changing Card 3 of Data Set Entry IV in Figure 36. The numbers used for these file-writing sequences are chosen by the user.

Fig. 36- Input to Program MARKOV (Sample Problem 2)

```
NOAA SEISMIC EXPOSURE MAP 1 ------------------------------------------------ I
 3  5.0        40.0        0.5  ------------------------------------------- II
SAMPLE SOURCE 2 ------------------------------------------------------------- III
3   1FILE  106.       000          8.05 ----------------------- Card 1 ]
  17 ------------------------------------------------------------ Card 2 ]-- IV
M1 -------------------------------------------------------------- Card 1 ]
 6 -------------------------------------------------------------- Card 2 ]
7.8       7.9        8.2        7.8        9.2        8.1 ------- Card 3 ]-- V
P         8.3         6.5       8.7         9.3       ----------- card 4 ]
M2
 4
8.4       8.3        9.1         8.4
P         8.3         8.5       8.7         9.3
M3
 2
8.2       8.7
P         8.3         8.5       8.7         9.3
T11 ------------------------------------------------------------- card 1 ]
 4 -------------------------------------------------------------- Card 2 ]
 2*        3.        1.         1. ------------------------------ Card 3 ]-- VI
P         50.0       75. L      100.L       28..0 --------------- Card 4 ]
112
 1
31.
P         55.0        80.0      110.0       300.0
113
 1
6.
P         60.0       85.0       120.0      320.0
T21
 2
1.         1.
P         60.0       115.0      155.3      410.0
T22
 1
1.
P         87.0       125.0      165.3      440.0
123
 1
19*
P         94. D      135.0      175.0      470.0
T31
 2
1.        1.
P         110. G     15 G.:     18..0      ● ec. r
T32
0
P         120.0      160.0      200.0      500.0
T33
0
P         13 L.?     170.0      22..0      520.0
SAMPLE SOURCE 3
3   1FILE  42.G      8.20       8.05
Ml-17
 6
7.8       7.9        E*2        7.8        9.2          8.1
P         a.3        8.5        8.7        9.3
M2
 4
8.4       8.3        9.1         8.4
P         8.3        8.5        8.7        9.3
M3
 2
●.z       8.7
P         0.3        8.5        8.7        9.3
T11
 4
2*        3.         1.         1.
P          58.        86.       115.       322.
712
 1
31.
P          63.       92.        127.       345.
```

Fig. 36- Input to Program MAR KOV (Sample Problem 2) (continued)

```
T13
 1
6.
P          69.      98.      138.      368.
T21
 2
1.         1.
P          92.      132.     178.      472.
T22
 1
1.
P          100.     144.     190.      506.
T23
 1
19.
P          108.     155.     201.      541.
T31
 2
1.         1.
P          127.     173.     207.      552.
132
0
P          138.     184.     230.      575.
T33
0
P          150.     196.     253.      598.
SAMPLE SOURCE 4
3   1FILE  15.0      9.2     8.05
  17
M1
 6
7.8        7.9      8.2      7.'3      9.2        8.1
P          8.3      8.5      8.7       9.3
M2
 4
8.4        8.3      9*1       6.4
P          8.3      8.5      8.7       9*3
M3
 2
8.2        8.7
P          6.3      8.5      8.7       9.3
111
 4
 2.         3.       1.       1.
P          56.      86.      115.      322.
T12

 1
31.
P          63.      92.      12?.      345.
113
 1
6.
P          69.      98.      136*      368.
T21
 2
1.          1.
P          92.      132.     178.      472.
122
 1
1.
P          101.     144.     190.      506.
T23
 1
19.
•          108.     155.     201.      541.
T31
 2
1.         1.
P          1279     173.     207.      552.
1s2
o
P          138.     184.     230.      57s.
T33
0
P          150.     196.     253.      598.
```

Fig. 37 — Output from Program MARKOV as Obtained on Line Printer

```
          SEMI MARKOV MODEL OF EARTHQUAKE RECURRENCE

 RUN DESCRIPTION - NOAA SEISMIC EXPOSURE MAP 1


ZONE  1 - SAMPLE SOURCE 2


INFORMATION WHICH APPLIES TO THIS ZONE
--------------------------------------

NUMBER OF STATES ....................................         3
MAGNITUDE OF THE LAST LARGE EARTHQUAKE ..............      8.00
                 MAGNITUDE RANGE INDEX ..............         1
TIME ELAPSED SINCE LAST LARGE EARTHQUAKE - YEARS ....    106.00
                                         - TIME PERIODS      21
ELAPSED TIME + PERIOD OF NONRECURRENCES - YEARS .....    146.[illegible]
                                     - TIME PERIODS .        29
NUMBER OF PARAMETERS IN THE SEMI-MARKOV MODEL .......        12
NUMBER OF SEGMENTS ..................................         1

EARTHQUAKE MAGNITUDES

  STATE INDEX   DISCRETE MAGNITUDE   MAGNITUDE RANGE
  -----------   ------------------   ---------------
       1              8.050           7.800 -  8.300
       2              8.550           8.300 -  8.800
       3              9.05?           8.800 -  9.300
```

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

BAYESIAN ESTIMATION OF MODEL PARAMETERS

PARAMETER 1 - M1

NUMBER OF DATA POINTS = 6
DATA VALUES -

7.800	7.900	8.200	l.soil	9.200	8.120

PRIOR FRACTILES ARE -

0.25 FRACTILE	0.50 FRACTILE	0.75 FRACTILE	1.00 FRACTILE
8.300	8.500	8.700	9.300

RESULTS OF COMBINING DATA AND PRIORS ARE AS FOLLOWS

	SAMPLE SIZE N	DEG. OF FREEDOM	MEAN (XBAR)	VARIANCE (SIGSQR)	FOURTH MOMENT	PARAMETER S SQUARE
OBJECTIVE DATA	6.0	5.0	-2.216	4.130		4.130
PRIOR DATA	5.0	4.0	-.4[illegible]	.298	.s'42	.124
POSTERIOR	11.0	10.0	-1.414	4.641		2.963

PARAMETER 2 - M2

NUMBER OF DATA POINTS = 4
DATA VALUES -

8.430	8.300	9.1[illegible]0	8.400

PRIOR FRACTILES ARE -

0.25 FRACTILE	0.50 FRACTILE	0.75 FRACTILE	1.00 FRACTILE
8.300	8.500	.700	9.3[illegible]

RESULTS OF COMBINING DATA AND PRIORS ARE AS FOLLOWS

	SAMPLE SIZE N	DEG. OF FREEDOM	MEAN (XBAR)	VARIANCE (SIGSQR)	FOURTH MOMENT	PARAMETER S SQUARE
OBJECTIVE DATA	4.0	3.0	-.3[illegible]	.161		.181
PRIOR DATA	5.0	4.0	-.4[illegible]	.298	.5[illegible]	.124
POSTERIOR	[illegible]	8.	-.413	.19[illegible]		[illegible]

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

PARAMETER 3 - M3

NUMBER OF DATAPOINTS = 2

DATA VALUES -

8.200 8.700

PRIOR FRACTILES ARE -

0.25 FRACTILE	0.50 FRACTILE	0.75 FRACTILE	1.00 FRACTILE
H.soil	8.500	8.700	9.300

RESULTS OF COMBINING DATA AND PRIORS ARE AS FOLLOWS

	SAMPLE SIZE N	DEG. OF FREEDOM	M E A N (XBAR)	VARIANCE (SIGSQR)	FOURTH MOMENT	PARAMETERS SQUARE
OBJECTIVE DATA	2.0	1.0	-.511	.329		.329
PRIOR DATA	5.0	4.0	-.452	.298	.592	.124
POSTERIOR	7.0	6.0	-.469	.237		.138

PARAMETER 4 - T11

NUMBER OF DATA POINTS = [illegible]

DATA VALUES -

2.000 5.000 1.000 1.000

PRIOR FRACTILES ARE -

9.25 FRACTILE	0.50 FRACTILE	0.75 FRACTILE	1.01 FRACTILE
50.000	75.000	100.000	280.000

RESULTS OF COMBINING DATA AND PRIORS ARE AS FOLLOWS

	SAMPLE SIZE N	DEG. OF FREEDOM	M E A N (XBAR)	VARIANCE (SIGSQR)	FOURTH MOMENT	PARAMETERS SQUARE
OBJECTIVE DATA	4.0	3.0	.448	.295		.295
PRIOR DATA	5.0	4.0	4.258	.512	1.464	.213
POSTERIOR	9.0	8.0	2.5[illegible]3	6.232		4.297

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

PARAMETER 5 - 112

NUMBER OF DATA POINTS = 1
DATA VALUES -
31.000

PRIOR FRACTILES ARE -

0.25 FRACTILE	0.50 FRACTILE	0.75 FRACTILE	1.00 FRACTILE
55.000	80.000	11[illegible].000	300.000

RESULTS OF COMBINING DATA AND PRIORS ARE AS FOLLOWS

	SAMPLE SIZE N	DEG. OF FREEDOM	MEAN (XBAR)	VARIANCE (SIGSQR)	FOURTH MOMENT	PARAMETER S SQUARE
OBJECTIVE DATA	1.0	.5	3.434	.000		.000
PRIOR DATA	5.0	4.0	4.333	.476	1.169	.19[illegible]
POSTERIOR	6.0	5.0	4.164	.57[illegible]		.293

PARAMETER 6 - 113

NUMBER OF DATA POINTS = 1
DATA VALUES -
6.000

PRIOR FRACTILES ARE -

0.25 FRACTILE	0.50 FRACTILE	0.75 FRACTILE	1.00 FRACTILE
60.000	85.00[illegible]	12[illegible].000	320.000

RESULTS OF COMBINING DATA AND PRIORS ARE AS FOLLOWS

	SAMPLE SIZE N	DEG. OF FREEDOM	MEAN (XBAR)	VARIANCE (SIGSQR)	FOURTH MOMENT	PARAMETER S SQUARE
OBJECTIVE DATA	1.[illegible]	[illegible]	1.7[illegible]	.[illegible]11		[illegible]
PRIOR DATA	[illegible]	4.0	4.4[illegible]1	.446	.954	.18[illegible]
POSTERIOR	[illegible]	[illegible]	3.5[illegible]3	[illegible].525		1.3[illegible]

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

```
PA RAMETER 7 - T21

NUMBER OF DA TA POINTS =          2
DATA VALUES
     1.000     1.000

PRIOR FRAC TILES ARE -
0.25 FRACTILE   0.50 FRACTILE   0.75 FRACTILE   1.00 FRACTILE

      80.000        115.000         155.000          410.000

RESULTS OF COMBINING DATA AND PRIORS ARE AS FOLLOWS

                  SAMPLE  DEG. OF   M E A N   VARIANCE   FOURTH   PARAMETER
                  SIZE N  FREEDOM   (XBAR)    (SIGSQR)   MOMENT   S SQUARE

OBJECTIVE DATA     2.0      111      .010      .000                .000
PRIOR DATA         5.0      4.0     4.614      .441      1.016     .18*
POSTERIOR          ?.0      6.0     3.353     9.?[4                5.369


PARAMETER 8  - T22

NUMBER OF DATAPOINTS =
DATA VALUES
     1.050

PRIOR FRACTILES ARE -
0.25 FRACTILE   0.50 FRACTILE   0.75 FRAC TILE   1.00 FRACTILE

      87.000        12?.00          16>.,."          440.000

RESULTS OF COMBINING DATA AND PRIORS ARE AS FOLLOWS

                  SAMPLE  DEG. OF   M E A N   VARIANCE   FOURTH   PARAMETER
                  SIZE N  FREEDOM   (XBAR)    (SIGSQR)   MOMENT   S SQUARE

OBJECTI VE DATA    1."       ..        .0       .030                .001
PRIOR DATA         5.0      4..     4.77?      .431       .992      .18
POSTERIOR          6.0      5.0     3.975     7.655                3.937
```

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

```
PARAMETER  9 - T23

NUMBER OF DATA P° NTS =
DATA VALUES -
    19.066

PRIOR FRACTIL S ARE  -
0.25 FRACTILE   0.50 FRACTILE   0.75 FRACTILE   1.0[illegible] FRACTILE
-------------   -------------   -------------   ---- --------
      94.000         135.[illegible]0[illegible]       17[illegible].3[illegible]          47[illegible].[illegible]0C

RESULTS OF COMBINING DATA AND PRIORS ARE AS FOLLOWS

                    SAMPLE   DEG. OF   M E A N    VARIANCE    FOURTH   PARAMETER
                    SIZE N   FREEDOM   (XBAR)    (SIGSQR)    MOMENT   S SQUARE
                    ------   -------   -------   --------    ------   ---------
OBJECTIVE DATA       1.0       .[illegible]       2.944       .[illegible]3[illegible]              .[illegible]
PRIOR DATA           5.0      4.0       4.841       .423      .[illegible]72    .176
POSTERIOR            6.0      5.0       4.525      1.440               .741


PARAME ER 10 -  3[illegible]

NUMBER OF DATA PO[illegible]N S =          2
DATA VALUES -
     1.006     [illegible]

PRIOR FRACTILES ARE  -
0.25 FRACTILE   0.50 FRACTILE   0.75 FRACTILE   1.0[illegible] FRACTILE
-------------   -------------   -------------   -------------
      110.000        15[illegible].50[illegible]        18[illegible].000          4[illegible].[illegible]0

RESULTS OF COMBINING DATA AND PRIORS ARE AS FOLLOWS

                    SAMPLE   DEG. OF   M E A N    VARIANCE    FOURTH   PARAMETER
                    SIZE N   FREEDOM   (XBAR)    ( IGSQR)    MOMENT   S SQUARE
                    ------   -------   -------   --------    ------   ---------
OBJECTIVE DA A       2.0      1.0      [illegible]       [illegible]00[illegible]              .[illegible]
PRIOR DATA           5.0      4.0      4.9[illegible]      [illegible].316      .54[illegible]    .131
POSTERIOR            7.0      6.[illegible]      3.5[illegible]8     [illegible]0.163              5.924
```

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

```
PARAMETER 11 - T32

NUMBER OF DATA POINTS =

PRIOR FRACTILES ARE
0.25 FRACTILE   0.50 FRACTILE   0.75 FRACTILE   1.00 FRACTILE
------------    -------------   -------------   -------------
   120.030         160.000         200.000         500.000

RESULTS OF COMBINING DATA AND PRIORS ARE AS FOLLOWS

                  SAMPLE  DEG. OF   M E A N   VARIANCE   FOURTH   PARAMETER
                  SIZE N  FREEDOM   (XBAR)    (SIGSQR)   MOMENT   S SQUARE
                  ------  -------   -------   --------   ------   ---------
OBJECTIVE DATA      .0       .0     .0.[illegible]      .00[illegible]              .[illegible]0[illegible]
PRIOR DATA         5.0      4.0     5.044      .29[illegible]      .45[illegible]     .1[illegible]3
POSTERIOR          5.0      4.0     5.044      .296                .12[illegible]


PARAMETER 12 - T33

NUMBER OF DATAPOINTS =

PRIOR FRACTILES ARE -
0.25 FRACTILE   0.50 FRACTILE   0.75 FRACTILE   1.00 FRACTILE
-------------   -------------   -------------   -------------
   130.000         170.000         22[illegible].000         52[illegible].000

RESULTS OF COMBINING DATA AND PRIORS ARE AS FOLLOWS

                  SAMPLE  DEG. OF   M E A N   VARIANCE   FOURTH   PARAMETER
                  SIZE N  FREEDOM   (XBAR)    (SIGSQR)   MOMENT   S SQUARE
                  ------  -------   -------   --------   ------   ---------
OBJECTIVE DATA      .0       .0     .0 [illegible]      .00[illegible]              .10[illegible]
PRIOR DATA         5.0      4.0     5.1[illegible]6      .278       .361     .11[illegible]
POSTERIOR          5.0      4.0     [illegible].1[illegible]6      .278                .11[illegible]
```

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

PROBABILISTIC CALCULATIONS IN THE SEMI-MARKOV MODEL

P(I,J)=PROBABILITY THAT THE NEXT EARTHQUAKE AFTER
ONE OF MAGNITUDE I WILL BE ONE OF MAGNITUDE J

P(1, 1)= .7888886	P(1,2)= .1422268	P(1, 3)= .[illegible]688827
P(2, 1)= .2866263	P(2,2)= .5676336	P(2, 3)= .[illegible]457401
P(3, 1)= .3524834	P(3,2)= .5143812	P(3, 3)= .[illegible]331354

H(I,J,M)=PROBABILITY THAT THE TIME BETWEEN EARTHQUAKES
MAGNITUDES I AND J, RESPECTIVELY, WILL BE EQUAL TO [illegible] 5.00 * M (+ OR - [illegible]) YEARS

H(1,1, 1)= .4173135	H(1,2, 1)= .0174706	H(1,3, 1)= .1354429
H(1,1, 2)= .0784656	H(1,2, 2)= .0223277	H(1,3, 2)= .0653548
H(1,1, 3)= .0519621	H(1,2, 3)= .0305105	H(1,3, 3)= .0554509
H(1,1, 4)= .0382544	H(1,2, 4)= .0375623	H(1,3, 4)= .0478219
H(1,1, 5)= .0298805	H(1,2, 5)= .0430134	H(1,3, 5)= .0417395
H(1,1, 6)= .0242707	H(1,2, 6)= .0460775	H(1,3, 6)= .0367862
H(1,1, 7)= .0202709	H(1,2, 7)= .048613[illegible]	H(1,3, 7)= .032688[illegible]
H(1,1, 8)= .0172886	H(1,2, 8)= .0490287	H(1,3, 8)= .0292533
H(1,1, 9)= .0149884	H(1,2, 9)= .0482312	H(1,3, 9)= .0263431
H(1,1, 10)= .0131665	H(1,2, 10)= .0465339	H(1,3, 10)= .0238538
H(1,1, 11)= .0116922	H(1,2, 11)= .0442157	H(1,3, 11)= .0217666
H(1,1, 12)= .0104780	H(1,2, 12)= .0415278	H(1,3, 12)= .0198412
H(1,1, 13)= .0094629	H(1,2, 13)= .0386569	H(1,3, 13)= .0182043
H(1,1, 14)= .0086034	H(1,2, 14)= .035744[illegible]	H(1,3, 14)= .0167733
H(1,1, 15)= .0078678	H(1,2, 15)= .0328877	H(1,3, 15)= .0155126
H(1,1, 16)= .0072321	H(1,2, 16)= .030153[illegible]	H(1,3, 16)= .0143727
H(1,1, 17)= .0066781	H(1,2, 17)= .0275794	H(1,3, 17)= .013[illegible]632
H(1,1, 18)= .0061916	H(1,2, 18)= .0251873	H(1,3, 18)= .0124576
H(1,1, 19)= .0057617	H(1,2, 19)= .0229843	H(1,3, 19)= .0116419
H(1,1, 20)= .0053794	H(1,2, 20)= .020969[illegible]	H(1,3, 20)= .0109045
H(1,1, 21)= .0050376	H(1,2, 21)= .0191345	H(1,3, 21)= .0102357
H(1,1, 22)= .0047305	H(1,2, 22)= .0174697	H(1,3, 22)= .0096271
H(1,1, 23)= .0044533	H(1,2, 23)= .015[illegible]62	H(1,3, 23)= .00[illegible]718
H(1,1, 24)= .0042022	H(1,2, 24)= .0146011	H(1,3, 24)= .00[illegible]
H(1,1, 25)= .0039736	H(1,2, 25)= .013371[illegible]	H(1,3, 25)= .00[illegible]972
H(1,1, 26)= .0037650	H(1,2, 26)= .0122604	H(1,3, 26)= .0076063
H(1,1, 27)= .0035740	H(1,2, 27)= .0112585	H(1,3, 27)= .0072726
H(1,1, 28)= .0033934	H(1,2, 28)= .0[illegible]3527	H(1,3, 28)= .00[illegible]74
H(1,1, 29)= .0032367	H(1,2, 29)= .0[illegible]334	H(1,3, 29)= .00[illegible]
H(2,1, 1)= .3573111	H(2,2, 1)= .2551141	H(2,3, 1)= .[illegible]
H(2,1, 2)= .[illegible]8112	H(2,2, 2)= [illegible]	H(2,3, 2)= [illegible]
H(2,1, 3)= .0412776	H(2,2, 3)= [illegible]	H(2,3, 3)= [illegible]
H(2,1, 4)= .0314245	H(2,2, 4)= .[illegible]31964	H(2,3, 4)= [illegible]
H(2,1, 5)= [illegible]	H(2,2, 5)= [illegible]	H(2,3, 5)= [illegible]
H(2,1, 6)= .[illegible]11695	H(2,2, 6)= [illegible]	H(2,3, 6)= [illegible]
H(2,1, 7)= [illegible]	H(2,2, 7)= [illegible]	H(2,3, 7)= [illegible]
H(2,1, 8)= [illegible]	H(2,2, 8)= [illegible]	H(2,3, 8)= [illegible]
H(2,1, 9)= [illegible]	H(2,2, 9)= [illegible]	H(2,3, 9)= [illegible]
H(2,1, 10)= [illegible]	H(2,2, 10)= .0137267	H(2,3, 10)= [illegible]

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

```
H(2,1,11)= .0111711    H(2,2,11)= .0124803    H(2,3,11)= .0257657
H(2,1,12)= .0101613    H(2,2,12)= .0114276    H(2,3,12)= .0244236
H(2,1,13)= .0093956    H(2,2,13)= .0105267    H(2,3,13)= .0231282
H(2,1,14)= .0085718    H(2,2,14)= .0097474    H(2,3,14)= .0218969
H(2,1,15)= .0079361    H(2,2,15)= .0090671    H(2,3,15)= .0207159
H(2,1,16)= .0073834    H(2,2,16)= .0084681    H(2,3,16)= .0196046
H(2,1,17)= .0068998    H(2,2,17)= .0079368    H(2,3,17)= .0185568
H(2,1,18)= .0064564    H(2,2,18)= .0074626    H(2,3,18)= .017571
H(2,1,19)= .0060686    H(2,2,19)= .0070371    H(2,3,19)= .016645
H(2,1,20)= .0057269    H(2,2,20)= .0066529    H(2,3,20)= .0157761
H(2,1,21)= .0054063    H(2,2,21)= .0063047    H(2,3,21)= .0149614
H(2,1,22)= .0051216    H(2,2,22)= .0059877    H(2,3,22)= .0141977
H(2,1,23)= .0048624    H(2,2,23)= .0056977    H(2,3,23)= .0134826
H(2,1,24)= .0046256    H(2,2,24)= .0054322    H(2,3,24)= .0128111
H(2,1,25)= .0044044    H(2,2,25)= .0051876    H(2,3,25)= .0121823
H(2,1,26)= .0042086    H(2,2,26)= .0049619    H(2,3,26)= .0115926
H(2,1,27)= .0040243    H(2,2,27)= .0047523    H(2,3,27)= .0110393
H(2,1,28)= .0038537    H(2,2,28)= .004559     H(2,3,28)= .0105211
H(2,1,29)= .0036955    H(2,2,29)= .0043786    H(2,3,29)= .0100325
H(3,1, 1)= .3248790    H(3,2, 1)= .0025443    H(3,3, 1)= .0026689
H(3,1, 2)= .0559384    H(3,2, 2)= .0023559    H(3,3, 2)= .0018723
H(3,1, 3)= .0387673    H(3,2, 3)= .0030844    H(3,3, 3)= .0024991
H(3,1, 4)= .0296446    H(3,2, 4)= .0039165    H(3,3, 4)= .0030656
H(3,1, 5)= .0239420    H(3,2, 5)= .0048545    H(3,3, 5)= .003789
H(3,1, 6)= .0200301    H(3,2, 6)= .0054980    H(3,3, 6)= .0045899
H(3,1, 7)= .0171778    H(3,2, 7)= .0070963    H(3,3, 7)= .0054629
H(3,1, 8)= .0150060    H(3,2, 8)= .0082903    H(3,3, 8)= .0064565
H(3,1, 9)= .0132976    H(3,2, 9)= .0096195    H(3,3, 9)= .0075122
H(3,1,10)= .0119194    H(3,2,10)= .011918     H(3,3,10)= .0086412
H(3,1,11)= .0107846    H(3,2,11)= .0124687    H(3,3,11)= .0098332
H(3,1,12)= .0098346    H(3,2,12)= .0139471    H(3,3,12)= .0111754
H(3,1,13)= .0090283    H(3,2,13)= .0154283    H(3,3,13)= .0123521
H(3,1,14)= .0083350    H(3,2,14)= .0168851    H(3,3,14)= .0136453
H(3,1,15)= .0077336    H(3,2,15)= .0182894    H(3,3,15)= .0149351
H(3,1,16)= .0072069    H(3,2,16)= .0196142    H(3,3,16)= .0162[illegible]
H(3,1,17)= .0067421    H(3,2,17)= .0208334    H(3,3,17)= .0174215
H(3,1,18)= .0063290    H(3,2,18)= .0219267    H(3,3,18)= .0185735
H(3,1,19)= .0059596    H(3,2,19)= .0228728    H(3,3,19)= .0198466
H(3,1,20)= .0056275    H(3,2,20)= .0236591    H(3,3,20)= .0206042
H(3,1,21)= .0053274    H(3,2,21)= .0242771    H(3,3,21)= .0214496
H(3,1,22)= .0050549    H(3,2,22)= .0247228    H(3,3,22)= .0221653
H(3,1,23)= .0048066    H(3,2,23)= .024996     H(3,3,23)= .0227436
H(3,1,24)= .0045793    H(3,2,24)= .0251044    H(3,3,24)= .0231811
H(3,1,25)= .0043707    H(3,2,25)= .0250552    H(3,3,25)= .0234742
H(3,1,26)= .0041785    H(3,2,26)= .024961     H(3,3,26)= .0236267
H(3,1,27)= .0040009    H(3,2,27)= .0245536    H(3,3,27)= .0236449
H(3,1,28)= .0038364    H(3,2,28)= .0240959    H(3,3,28)= .0235435
H(3,1,29)= .0036837    H(3,2,29)= .0235569    H(3,3,29)= .0233226

EARTHQUAKE PROBABILITIES FOR THE NEXT     5.0 YEARS

PROBABILITY   NO. OF EARTHQUAKES OF EACH MAGNITUDE
               7.8-8.3 8.3-8.8 8.8-9.3
  .96975772       0       0       0
  .01640478       1       0       0
```

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

.01092240	0	1	0
.00291510	0	0	1

EARTHQUAKE PROBABILITIES FOR THE NEXT 10.0 YEARS

PROBABILITY	NO. OF EARTHQUAKES OF EACH MAGNITUDE 7.8-8.3	8.3-8.8	8.8-9.3
.94158687	0	0	0
.02625387	1	0	0
.01819287	0	1	0
.00540068	2	0	0
.00532359	0	0	1
.00158169	0	2	0
.00109676	1	1	0
.00048687	1	0	1
.00307600	0	1	1
.00000080	0	0	2

EARTHQUAKE PROBABILITIES FOR THE NEXT 15.0 YEARS

PROBABILITY	NO. OF EARTHQUAKES OF EACH MAGNITUDE 7.8-8.3	8.3-8.8	8.8-9.3
.91529242	0	0	0
.03441904	1	0	0
.02425734	0	1	0
.00965783	2	0	0
.00753597	0	0	1
.00298314	0	2	0
.00196917	1	1	0
.00177798	3	0	0
.00094524	1	0	1
.00036501	2	1	0
.00022905	0	3	0
.00019218	0	1	1
.00017781	2	0	1
.00016145	1	2	0
.00001979	1	1	1
.00001115	0	2	1
.00000025	1	0	
.00000019	0	0	
.00000005	0	1	2

EARTHQUAKE PROBABILITIES FOR THE NEXT 20.0 YEARS

PROBABILITY	NO. OF EARTHQUAKES OF EACH MAGNITUDE 7.8-8.3	8.3-8.8	8.8-9.3
.89079256	0	0	0
.04134539	1	0	[illegible]
.0293779	0	1	
.01362719	2	[illegible]	
.00958317	[illegible]	[illegible]	

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

.00434562	[illegible]	2	[illegible]
.00351354	3	0	[illegible]
.00281754	1	1	[illegible]
.00142568	1	0	1
.00072816	2	1	0
.00058534	4	0	[illegible]
.00048248	0	3	[illegible]
.00038782	2	0	1
.00034855	0	1	1
.00032835	1	2	0
.00012146	3	1	0
.00006431	3	0	1
.00005399	2	2	0
.00004990	1	1	1
.00003317	0	4	0
.00003357	0	2	1
.00002376	1	3	0
.00000811	1	0	2
.00000785	2	1	1
.00000435	0	0	2
.00000293	1	2	1
.00000162	0	3	1
.00000159	2	0	2
.00000016	0	1	2
.00000010	1	1	2

EARTHQUAKE PROBABILIT ES FOR THE NEXT 25.0 YEARS

PROBABIL TY	N°. OF EARTHQUAKES OF EACH MAGNI UDE .8-8.3	8.3-8.8	8.8-9.3
.86765619	0	0	0
.04729702	1	0	[illegible]
.03373078	[illegible]	1	[illegible]
.01731331	2	0	[illegible]
.01148524	0	0	1
.00564697	0	2	[illegible]
.00530531	[illegible]	0	[illegible]
.00365320	[illegible]	1	[illegible]
.00191904	[illegible]	0	1
.00126668	4	0	0
.00112006	2	1	[illegible]
.00076103	0	3	[illegible]
.00061365	[illegible]	0	1
.00054183	[illegible]	1	1
.00051517	1	[illegible]	[illegible]
.00026651	[illegible]	1	
.00014270	[illegible]	[illegible]	
.00015147	[illegible]	[illegible]	1
.00012081	[illegible]	2	[illegible]
.00009 71	[illegible]	1	1
.00017713		[illegible]	[illegible]
.000[illegible]		[illegible]	[illegible]
.00005[illegible]7	1	[illegible]	[illegible]
.00004941	4	1	[illegible]
.00[illegible]02[illegible]7	4	[illegible]	1

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

.00002116	2	1	1
.00001895	3	2	
.00001447	1	0	2
.00000868	1	2	1
.00000794	2	3	0
.00000743	0	0	2
.00000483	0	3	1
.00000480	0	5	0
.00000424	2	0	2
.00000350	1	4	0
.00000303	3	1	1
.00000117	2	2	1
.00000072	3	0	2
.00000043	1	3	1
.00000038	0	1	2
.00000033	1	1	2
.00000024	0	4	1
.00000096	2	1	2
.00000003	0	2	2
.00000001	1	2	2

EARTHQUAKE PROBABILITIES FOR THE NEXT 30.0 YEARS

PROBABILITY	NO. OF EARTHQUAKES OF EACH MAGNITUDE 7.8-8.3	8.3-8.8	8.8-9.3
.84602108	0	0	0
.05243002	1	0	1
.03743771	0	1	0
.02971887	2	0	0
.01325686	0	0	1
.00710174	3	0	0
.00687567	0	2	0
.00448261	1	1	0
.00241805	1	0	1
.00293682	4	0	0
.00153667	2	1	0
.00105403	0	3	0
.00086886	2	0	1
.00076846	0	1	1
.00071613	1	2	0
.00045321	5	0	0
.00043811	3	1	0
.00025771	3	0	1
.00020222	2	2	0
.00014104	1	1	1
.00013089	0	4	0
.00009678	0	2	1
.00039672	4	1	0
.00009151	1	3	0
.00006344	6	0	0
.00005851	4	[illegible]	1
.00004417	3	0	[illegible]
.00004021	2	1	1
.00002216	1	3	[illegible]
.00001979	2	3	0

Fig. 3 — Output from Program MARKOV as Obtained on Line Printer (continued)

.00001575	1	2	1
.00001345	5	1	0
.00001223	0	5	0
.00001163	0	0	2
.00000990	0	3	1
.00000877	1	4	1
.00000468	3	1	1
.00000822	5	0	1
.00000793	2	0	2
.00000603	4	2	0
.00000343	2	2	1
.00000268	3	3	5
.00000203	3	0	2
.00000130	1	3	1
.00000118	2	4	0
.00000115	4	1	1
.00000076	0	4	1
.00000074	0	1	2
.00000072	1	1	2
.00000070	0	6	
.00000051	1	5	0
.00000045	3	2	1
.00000031	4	0	2
.00000019	2	1	2
.00000017	2	3	1
.00000007	0	2	2
.00000006	1	4	1
.00000005	1	2	2
.00000003	0	5	1
.00000003	3	1	2
.00000001	1	0	3
.00000001	2	0	3

EARTHQUAKE PROBABILITIES FOR THE NEXT [illegible] YEARS

PROBABILITY	NO. OF EARTHQUAKES OF EACH MAGNITUDE 7.8-8.3	8.3-8.8	8.8-9.3
.82567155	0	0	0
.05687107	1	0	0
.04059875	0	1	0
.02385349	2	0	0
.01490939	0	0	1
.00886944	3	0	0
.00802669	0	2	0
.00530890	1	1	0
.00291721	1	0	1
.00286388	4	0	0
.00197557	2	1	0
.00135401	0	3	0
.00114062	2	0	1
.00102487	5	1	1
.00093386	1	2	0
.00077291	5	0	0
.00063335	3	1	0
.00058262	3	0	1

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

.00029726	2	2	0
.00020288			
.00019222	0	4	
.00016910	4		0
.000[illegible]61[illegible]2	6	0	0
.00014363	0	2	1
.00013602	1	3	0
.00010607	4	0	1
.00007947	3	2	1
.00006539	2	1	1
.00005575	2	3	1
.00003485	5	1	0
.00003106	1	0	2
.00002669	1	2	1
.00002245	5	0	1
.00002218	3	5	0
.00002089	7	0	0
.00001733	3	1	1
.00001715	0	0	2
.00001704	0	3	1
.00001599	1	4	0
.00001596	4	2	0
.00001265	2	0	2
.00000721	3	3	0
.00000699	2	2	
.00000447	6	1	1
.00000399	3	0	2
.00000349	4	1	1
.00000321	2	4	0
.00000291	6	0	1
.00000275		3	
.00000202	0	2	
.00000193	[illegible]	6	
.00000164	[illegible]	4	1
.00000141	3	2	1
.00000141	1	5	[illegible]
.00000133	1	1	[illegible]
.00000130	[illegible]	1	[illegible]
.00000092	4	0	[illegible]
.00000090	4	3	[illegible]
.00000055	2	3	1
.00000043	2	1	2
.00000043	5	1	1
.00000040	3	4	[illegible]
.00000021	1	4	1
.00000017	2	5	[illegible]
.00000017	4	2	1
.00000014	0	2	2
.00000013	5	0	2
.00000012	1	2	2
.00000012	0	5	1
.[illegible]16	0	7	
.[illegible]10	3	1	2
.[illegible]08	1	6	
.[illegible]07	3	3	1
.[illegible]03	2	2	2
.[illegible]03	[illegible]	[illegible]	[illegible]

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

.00002003	1	0	3
.00000003	2	4	1
.00000001	4	1	2
.00000001	0	3	2
.00000001	3	0	3

EARTHQUAKE PROBABILITIES FOR THE NEXT 40.00 YEARS

PROBABILITY	NO. OF EARTHQUAKES OF EACH MAGNITUDE		
	7.8-8.3	8.3-8.8	8.8-9.3
.80649714	0	0	0
.06071218	1	0	0
.04329350	0	1	0
.0?672915	2	0	0
.01605192	0	0	1
.01058673	3	0	0
.00909893	0	2	0
.00613?46	1	1	0
.00372472	4	0	0
.00341.?34	1	0	1
.00243469	2	1	0
.00165565	0	3	0
.00142426	2	0	1
.00130?61	0	1	1
.00116591	1	2	0
.00113042	5	0	0
.0008503*	3	1	0
.000s2225	3	0	1
.0004053s	2	2	0
.00029038	6	0	0
.00027346	1	1	1
.00025947	0	4	0
.00025669	4	1	0
.00019942	0	2	1
.0001 s732	1	3	0
.00016 -70	4	0	1
.00012124	3	2	0
.000096?5	2	1	1
.0.7006454	5	1	0
,00005697	7	0	0
.00005591	2	3	0
.00004293	5	0	1
.00004106	1	0	2
.00003925	1	2	1
.00003440	0	5	0
.00003011	4	2	0
.000029?9	3	1	I
.00002638	0	3	1
.000025? I	1	4	0
.00002421	0	0	2
.00001833	2	0	2
.00001380	3	3	0
.00001248	6	1	0
.00001703	2	2	1
.00600052	6	0	1

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

.00000739	4	1	1
.00000688	8	0	
.00000661	3	[illegible]	2
.00000621	2	4	
.00000574	5	2	[illegible]
.00000471	1	3	1
.00000371	6	6	[illegible]
.00000301	3	2	1
.00000296	6	4	1
.00000275	1	5	0
.00000261	4	3	0
.00000219	1	1	2
.00000211	0	1	2
.00000190	4	0	2
.00000149	7	1	0
.00000138	5	1	1
.00000123	2	3	1
.00000117	3	4	[illegible]
.00000103	7	0	1
.00000081	2	1	2
.00000067	6	2	0
.00000057	4	2	1
.00000052	2	5	0
.00000046	1	4	1
.00000040	5	0	2
.00000030	5	3	0
.00000030	0	7	2
.00000027	0	5	1
.00000026	0	2	2
.00000024	1	2	2
.00000023	3	1	2
.00000023	3	3	1
.00000023	1	6	0
.00000016	6	1	1
.00000013	4	4	0
.00000009	2	4	1
.00000007	2	2	2
.00000006	5	2	1
.00000006	3	5	5
.00000005	2	9	3
.00000005	6	0	2
.00000005	4	1	2
.00000005	1	0	3
.00000003	1	5	1
.00000003	0	3	2
.00000003	4	3	1
.00000003	2	6	[illegible]
.00000002	3	[illegible]	[illegible]
.00000002	1	[illegible]	[illegible]
.00000002	[illegible]	6	1
.00000002	3	[illegible]	[illegible]
[illegible]	[illegible]	8	
[illegible]	[illegible]	[illegible]	3
[illegible]	1	7	
[illegible]	[illegible]	[illegible]	1

Fig. 37 – Output from Program MARKOV as Obtained on Line Printer (continued)

MARGINAL PROBABILITIES

SEGMENT 1
PROPORTION =1.0000
OUTPUT UNIT 17

NUMBER OF EARTHQUAKES

DISCRETE MAGNITUDE	0	1	2	3	4	5	6	7	8
8.650	.8798585	.0719999	.0311855	.0121353	.0041888	.101) '.38	.0003123	.00[illegible]595	.[illegible]0069
8.550	.9318633	.0547676	.0110829	.0019482	.0002957	.000[illegible]38[illegible]	.0000042	.000[illegible]003	
9.050	.9758666	.0240347	.00[illegible]0986	.0000002					

Fig. 38 – Output for Program MARKOV as Saved on File for Input to Program SEISMIC. EXPOSURE

```
SAMPLE SOURCE 2                                                    SEGMENT 1      Heading
3   8.0500     .5000       40.001,00000000   No. of States, Beginning Markov
                                             Magnitude, Magnitude Increment,
                                             Time Period of Interest, Proportion
                                             of Segment Area to Entire
                                             Subduction Zone Area

       8          7          3   No. of probabilities for each state             Probability of 0, 1, ...9
 ,8788585  ,0719999  .0311855  .0121350  .0041888  ,0012530  .0003123  .0000595  occurrences of M=8.0
 .0000069                                                                        earthquake in next 40 years

 ,9310633  .0547676  .0110029  .0019402  .0002957  ,0000360  .0000040  .0000003  Probability of 0, 1, 2, 3, 4 occurrences
 .9750666  .0240347  .0000986  .0000002  Probability of 0, 1, 2 occurrences      of M=8.4 earthquake in next 40 years
                                         of M=8.8 earthquake in next 40 yrs.

SAMPLE SOURCE 3                                                    SEGMENT 1
3   8.0500     .5000       40.001,00000000
       8          7          3
 ,8228836  .1051228  .0456769  .0177976  .0061375  .0018362  .0004577  .0000075
 ,0000102
 ,6966504  .0840819  .0161201  .0026962  ,0003903  .0000480  .0000048  .0000004
 .9679829  .0310976  .0001194  ,0000002
SAMPLE SOURCE 4                                                    SEGMENT 1
3   8,0900     ,5000       40.001.00000000
       8          6          2
 .9390654  .0356773  .0158150  ,0063059  ,0022332  ,0006872  .0001766  ,0000350
 .0000043
 .9705201  .0240979  ,0039337  .0005607  .0000710  ,0000078  ,0000007
 .9922402  ,0077404  .0000194
```

Fig. 39 – Input to Program SEISMIC · EXPOSURE using Results from Program MARKOV (Sample Problem 2)

```
@RUN,W HAZRUN,,,100,200/5000
@SYM,F PRINT$,,PAZ
@SYM,D PRINT$
@BKI,A HAZSP2.
@HDG,N .M,66,4,2
@ASG,A NEWHAZ.
@ASG,A LCS*SP-SAOUT2.,///256
@ASG,A LCS*SM-MOUT.
@USE 17.,LCS*SM-MOUT.
@USE 26.,LCS*SP-SAOUT2.
@ASG,T 11.
@XQT NEWHAZ.NEWXQT
SAMPLE SEISMIC EXPOSURE MAPS    APRIL 1982
MARKOV INPUT USED
   30     1
   35.00      67.00     -153.00    2500000.0
    1.0        1.0        1.0        1*O        20.0        2.0        1.0
 -163.00      52.0
    4    1    16    4    1    1    2    11    1    26    0    0    5    5(    9
    3   18    1    1    0    0
   40.0       0.S       5.05
    1  -161.89    54.38    -40.0
    2  -160.00    52.85    -20.0
    3  -158.48    55.70    -40.00
    4  -156.44    54.20    -?0.0
    5  -156.12    53.96    -20.0
    6  -153..?9   55.35    -20.(
    7  -155.77    57.03    -40.00
    8  -152.08    58.81    -40.00
    9  -147.78    57.22    -20.0
   10  -146.41    58.90    -20.0
   11  -150.07    61.63    -40.0
   12   -148.46    57.53   -20.0
   13   -156.00    60.2     -5.0
   14   -154.0     60.7     -5*(I
   15   -152.5     60.7     -5.0
   16   -151.0     61.0     -5.0
    4    3    1    ?
    6    7    3    5
   12    8    7    6
   10   11    n    9
SAMPLE SOURCE  1                                        6    0
    1    1    1    0    0
    1
75.       22.789    13.739    5.457    2.183    0.851    0.514    0.0460
```

1

Job Control Language (JCL)

Fig. 39 – Input to Program SEISMIC · EXPOSURE using Results from Program MAR KOV (Sample Problem 2)(continued)

Input Necessary to Read MARKOV Input

NB NBSM INDATA

```
SAMPLE SOURCE 2                                                          6    3   17
      1     1     1     1     0
      1
75.        56.546    34.09    13.431     5.416     2.111     1.274     0.114
SAMPLE SOURCE 3                                                          6    3   17
            1     1     1     1
      :
75.0       55.588    33.512    13.311    5.3'4     2.075     1.253     0.112
SAMPLE SOURCE 4                                                          6    3   17
      1     1     1     1     0
      1
75.        81.6?7    49.241    19.559    7.823     3.949     1.841     0.165


SAMPLE LINE SOURCE 1                                                     7
      3    13     0     0
75.0       247.5     174.98    72.53     32.46     12.53     6.225     2.025
1.2
ACCEL    CM/SEC/SEC  40.0      10C.      150.0
190.67    .823308  0 .       1.561?72   .568
210.0      .5       0.       0.85      .606
         85   3.0      -06.0    0.864S    0.*626    15.0     15.1      0.1
2.7         4.7      8.4      15.0      27.0      47.0      90.       180.
225.
2*7         4.7      8.4      15*O      27.0      47.0      50.       70.0
 00.0
SEISMIC EXPOSURE MAP GROUND MOTION VALUES - SAMPLE PROBLEM
'156.0     58.0
      0     0     0     0
@PRINTFILE 11.
@BK2.N
@SYM.D PRINTS
```

7.5.4 Output from SEISMIC.EXPOSURE

As an illustration, the output from the program SEISMIC. EXPOSURE is shown for the site in Figure 40. If exposure was being considered at more than one site, as in Sample Problem 1, output from the SEISMIC.EXPOSURE program could be the input for the program CONST.PROB. Then seismic exposure levels expressed as contours for plotting could be generated by the Program PLOT.ISO, as in Sample Problem 1, given the input grid of points to contour.

Figure 41 shows the line-printer output for the one site example, with the output saved on disk as obtained on the line printer for plotting shown in Figure 42.

The values shown in Figure 42 (if generated for a grid of points) would be further processed by CONST.PROB and PLOT.ISO to obtain a seismic exposure plot for the subduction-zone tectonic environment shown in Figure 35.

8.0 DISCUSSION

This is the first of two volumes that document the project of developing software and applying the software initially to the Gulf of Alaska study region. The focus in this volume has been on the description of data inputs required to suitably characterize an area for implementation of the seismic-exposure software package. As such, it is a User Manual containing considerable detail.

The Appendices provide helpful details of methods and procedures that may be only summarized in the text. In particular, Appendix E discusses the data format of documented sensitivity runs, SEISMIC.EXPOSURE program computer code, input data, and suggestions for program variable modifications if a smaller (CPU requirement) program package is desired by a user.

The results developed in this work are general and can be used to obtain single-point values of seismic exposure at a site, or, by using a series of sites, seismic exposure maps can be obtained. For a single site or grid of sites, several levels of exceedance criteria, and up to 13 ground-motion parameters, can be evaluated in a single computer run.

This capability and the ability of the SEISMIC.EXPOSURE software program to accommodate subduction-zone-type tectonic environments, which may have seismic gaps, represent a significant improvement over previous methods of computing seismic exposure in such tectonic environments.

Volume II of the project documentation is a description of the procedures used in the development of the subjective inputs and historical data for use in the initial application of the software package. The inputs were developed by the SRU

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Volume II of the project documentation is a description of the procedures used in the development of the subjective inputs and historical data for use in the initial application of the software package. The inputs were developed by the SRU participants and implemented by Woodward-Clyde Consultants to produce six seismic exposure maps for the Gulf of Alaska region. When using Volume II, it may be useful to refer to Volume I in order to understand the details of the inputs and outputs used in the generation of the first-application seismic exposure maps.

APPENDIX A

PROCEDURES FOR USE OF GEOLOGIC AND SEISMOLOGIC DATA

As indicated in Figure A-1, to begin the seismic exposure evaluation process, it is necessary to establish the initial seismicity conditions for input into the model for analysis. The conditions that identify the geometry of earthquake sources, maximum magnitudes from the sources, and the respective recurrence rates must be established on the basis of best available data and information on the seismology and geology of the area of interest.

A.1.0 SOURCE SEISMICITY CHARACTERIZATION

Identification of earthquake sources can proceed after review of pertinent literature. For example, an earthquake source can be defined as an active geologic structure that has deformed, or is inferred to have deformed, Holocene-age sediments, or apparently unconsolidated sediments for which a specific age determination may not be available.

The nature of seismicity data that can be used for such evaluations is discussed below. This criterion may not permit the classification of all known geologic structures. However, such a strict division into active or inactive is not required, because on many such faults (based on other data) the inferred probability of earthquakes may be so low that the seismic exposure is not altered significantly in an area.

A.1.1 Correlating Earthquakes with Faults

As part of the process of defining fault locations and activity levels, local earthquakes may be correlated with mapped or

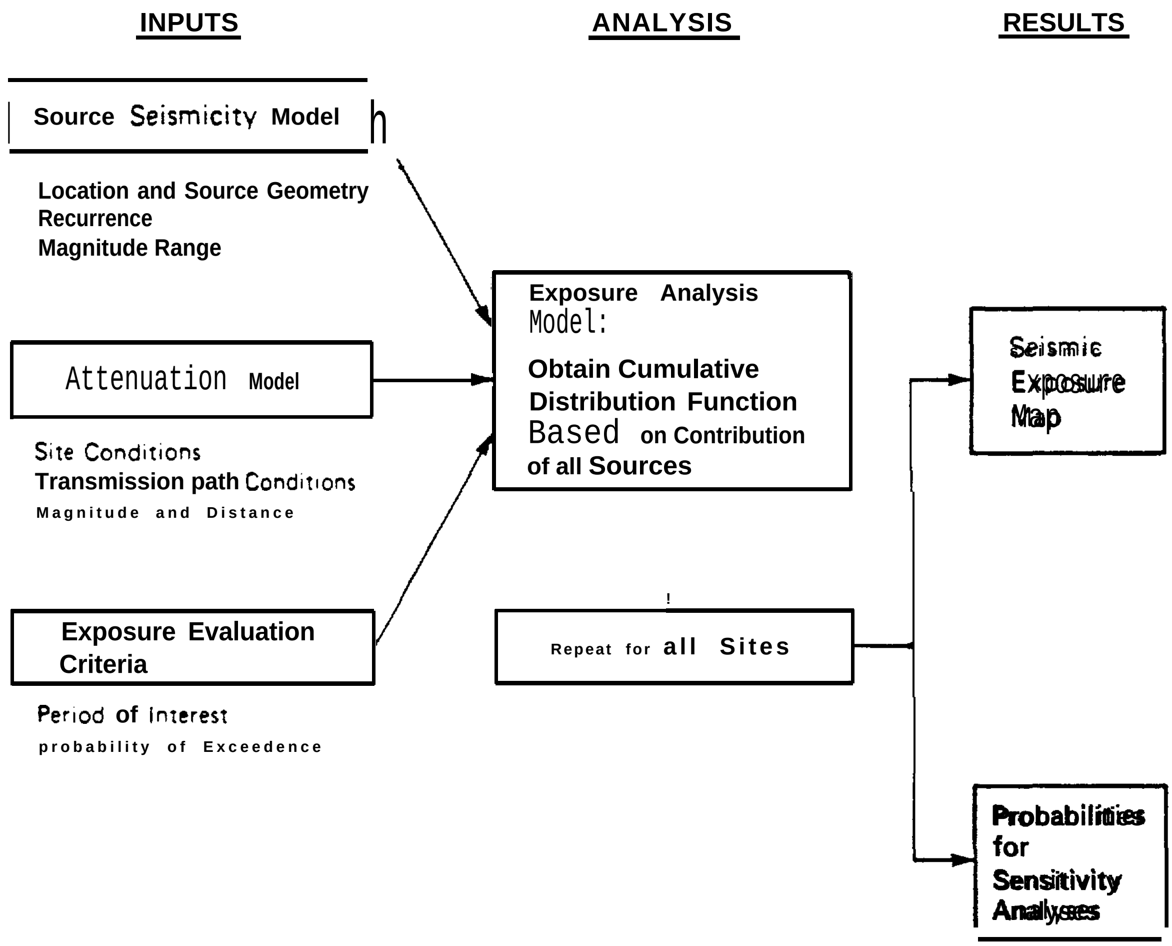


Fig. A-1 - Schematic Diagram of the Elements of a Seismic Hazard Evaluation - as Implemented in the SEISMIC EXPOSURE Software Package (same as Fig. 1, Vol. 1) inferred faults by using data obtained through dense seismograph networks. These networks permit more accurate hypocentral locations than do the standard teleseismic location techniques required for locating moderate and large earthquakes. Such methods do not take into account local factors that may affect the accuracy of the locations. In particular, the anomalous velocity structure of the subduction zone in Alaska (Jacob, 1973) has undoubtedly resulted in the dislocation of events that occur near the plate boundary between the North American and Pacific Ocean plates. Systematic dislocations of earthquakes associated with the Benioff zone of Japan and Tonga have commonly been observed (Utsu, 1967; Mitronovas and others, 1969). As a consequence, focal depths may be in error by as much as 50 km, while epicentral locations may be accurate to ± 25 km. However, these location accuracies may be sufficient in most areas of Alaska to show enough general seismicity features for seismic exposure evaluation.

Taking into account the possible errors in hypocenters and the available data used to define the active parts of faults, fault geometries can be established to model earthquake sources in the seismic-exposure mapping process. Lateral extent, fault orientation, depth of fault plane, style of faulting, slip-rate, and maximum earthquake potential for a given structure can be summarized and used in refining source models. Some types of sources, such as wide zones of deformation or sub-parallel faulting, may need to be represented by a series of parallel planes of appropriate dips.

Maximum earthquakes on faults may be assessed using the historical record and published correlations that relate maximum acceleration, earthquake magnitude, and distance (closest point on the surface rupture to the site). Lack of knowledge of the geologic environment and seismicity may require use of professional judgment to guide the choice of maximum-magnitude earthquake potential for a given source. Once earthquake source geometries and maximum-magnitude earthquakes have been estimated, earthquake recurrence rates must be established for each source.

To correlate earthquake epicenters with geologic features, an epicenter map overlay is placed over a base map showing faults or zones identified as earthquake sources for the region of interest. Epicenters are then correlated with geologic features by taking into consideration their location with respect to the sources selected earlier in the process. Focal depths are recorded for these earthquakes and used later to further delineate the relation between earthquakes and specific geologic structures.

A.1.2 Earthquake Recurrence

After earthquakes are tabulated for each source, the data are plotted. Where possible, Gutenberg and Richter's (1954) frequency-magnitude relationship is obtained. The upper limit of the magnitude range, given in the source characterization tables, is used for cut-off magnitudes for each source. For some sources, sufficient data are available for a linear fit, but for other sources, either data are insufficient or the distribution of events does not permit a linear fit by least-squares or maximum-likelihood estimates. In such cases, it may be necessary to estimate subjectively the level of activity of a feature by making comparisons with better understood faults and checking the consistency with regional seismicity patterns.

As indicated in Figure A-1, the seismic-exposure evaluation process requires input of recurrence parameters: the mean number of earthquakes occurring during a period of interest and the relationship between the number of earthquakes expected to occur during the period of interest within each of the chosen bands of earthquake magnitudes. In this work, the bands are subdivided into discrete magnitude widths (e.g., 0.25 or 0.4), as obtained from a magnitude-frequency relationship (N-M). A typical N-M relationship is shown in Figure A-2. The relationship shows the number of earthquakes greater than a given surface magnitude, M_s. The number is usually normalized to a unit area (1,000 sq km) and unit time (one year).

In areas of high seismicity near plate boundaries, for instance, available data provide a satisfactory basis for establishing the N-M relationship for earthquake magnitudes smaller than approximately Ms 7 3/4. For larger magnitudes and seismic gaps, available data are inadequate and supplemental analyses are required. Moreover, in some areas of low seismicity near plate boundaries, and in areas away from plate boundaries, available historical seismicity data may not be adequate; as a consequence, the data need to be supplemented by subjective judgments.

In order to make a subjective evaluation, an assessment is made of both the level of activity and the relative distribution of large-magnitude earthquakes to small-magnitude earthquakes for each case. Data points from the historical record form the bases for the subjective evaluations. The seismic-exposure mapping procedure does not require a log-linear relationship such as the Gutenberg-Richter relationship. In most cases, the N-M relationship used is multi-linear in character, with steep slopes near the upper magnitudes.

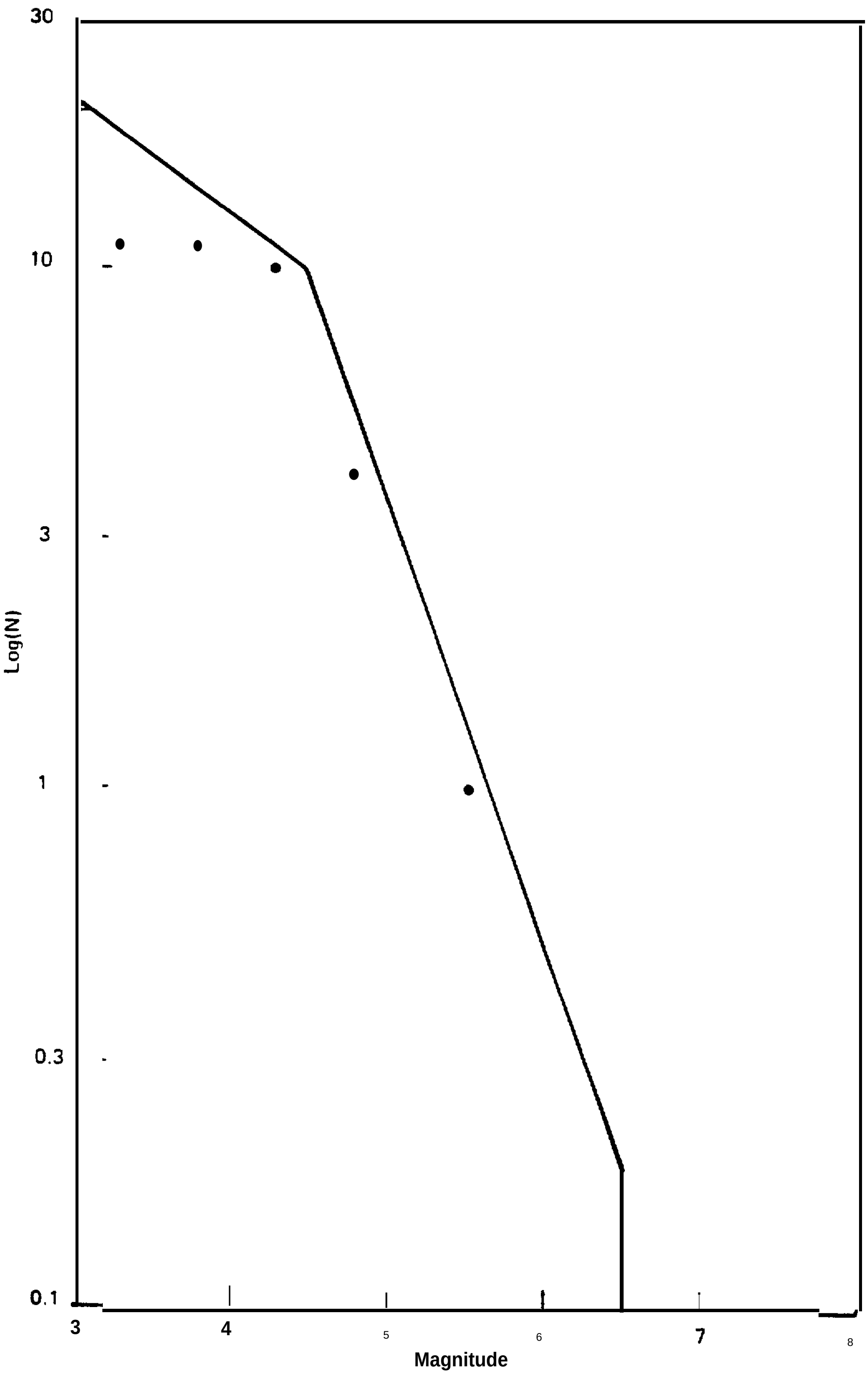


Fig. A-2 –Recurrence Relationship for Line Source 1
(same as Fig. 24)

A. 1.2.1 Subduction Zones and Seismic Gaps

Recurrence of earthquakes on subduction zones or in "seismic gaps" cannot be estimated realistically by mere extrapolation of the magnitude-frequency relations. Sufficient eviaence is available to indicate that large earthquakes occur in accordance with a physical process of gradual strain accumulation at a fairly uniform rate, ana sudaen release through earthquakes and aftershocks. This process is shown schematically in Figure A-3. Some strain may also be released through graoual aseismic creep. However, most of the energy release occurs through large earthquakes. Thus, given a large earthquake at the present time, the likelihood of another large earthquake in the rupture zone of the first one is considered to be very small for a certain period of time. As the elapsed time increases since the last large earthquake, the probability of another large earthquake also increases.

The commonly used Poisson process of earthquake occurrences cannot represent the time and space dependencies of the occurrence of large earthquakes on a subduction zone. The basic parameter of a Poisson process is the mean number of earthquakes of a given magnitude per unit time estimatea from historical seismicity data. It is assumed that the same mean rate is applicable to future earthquakes. Because the waiting time between large earthquakes may be quite long (several hundred years), the mean number of earthquakes over a long period of time may not be representative of the stochastic process of occurrences of large earthquakes.

A.1.2.2 Establishing Recurrence of Large Earthquakes

One approach, that avoids this over-conservative view of recurrence, establishes the probabilities of the occurrence of large earthquakes (Ms > 7-3/4) to occur on a subduction zone within a future time period directly on the basis of experience and judgments of seismologists. This approach, assessing probabilities on the basis of experience and judgment of qualified individuals, is consistent with the Bayesian (personalistic) concept of probabilities. These probabilities can then be converted to the mean number of events over a specified future period of time (now under the assumption of Poisson rate of occurrence), in a manner consistent with the earlier discussion for earthquakes of Ms $\leq$ 7-3/4.

A second approach can be used to characterize the probabilities and number of various magnitude earthquakes occurring in the subduction zone or "seismic gaps" over a given period of time in the future. This second approach generates a semi-Markov simulation that combines the data on the waiting times and magnitudes of recent large earthquakes.

Initial seismicity conditions consist of the time to since the most recent large magnitude earthquake and the magnitude M_o of the last large earthquake in a region on a subduction zone (or in a "seismic gap"). These variables, to and M_o, are inputs to the program MARKOV, which generates recurrence information on large earthquakes starting at a magnitude selected by the user. The program uses the initial seismicity conditions to generate a distribution on the transition probabilities between magnitude states (P_{ij}) and distribution on the holding times (h_{ij} [m]) between successive magnitude states. These distribution functions vary as a function of M. and to. The MARKOV output (input to SEISMIC.EXPOSURE) consists of the probabilities of discrete magnitude states and the number of occurrences of earthquakes of specific magnitudes over the time period of interest.

A.2.0 DISCUSSION

The goal of any seismic-exposure analysis is an end product that (as accurately as the data permit) reflects the level of knowledge of the tectonic processes in the region of interest. Hence, considerable effort should be spent in carefully examining the geologic and seismologic assumptions that characterize the sensitivity environment for a given seismic-exposure analysis. Uncertainties regarding the location and geometry of potential earthquake sources can be accommodated by geographically defining the exposure evaluation and through sensitivity analyses.

To refine the level of confidence in earthquake recurrence data, the available data for given sources may be compared and contrasted with more well-known regional faults or with world-wide data from a similar tectonic environment. The historical data above may be insufficient to adequately describe estimated future recurrence of seismicity. In such cases, the subjective arguments that have a firm geologic and seismologic basis may be used to suitably modify or supplement this lack of knowledge of recurrence data. This process can be implemented formally using personalistic probability theory or the semi-Markov characterization developed in this work.

APPENDIX B

SEISMIC.EXPOSURE SOFTWARE ORGANIZATION

B.1.0 SEISMIC.EXPOSURE PROGRAM - DESCRIPTION OF SUBROUTINES

The SEISMIC.EXPOSURE program has been divided into a main routine with a series of subroutines. A brief description of each subroutine is given in the following paragraphs, and a macro-flow chart of the program SEISMIC.EXPOSURE is presented in order to concisely show the overall logic of the program. The flow chart is shown in Figure B-1.

Input: Reads all the data sets discussed in Section 3.1, except for Data Sets XV and XVI.

Function LMBRT and CONFRM: Transforms nodal coordinates from degrees longitude and latitude to kilometers, for the purpose of plotting.

INITIA: Reads fault rupture lengths, generates magnitudes for output purposes, computes coefficient "C" in attenuation relationship(s). Checks whether point source model or rupture model is required, and whether attenuation is to be considered probabilistically or deterministically.

Function GAUSS: Evaluates the integral of the normal distribution $f_X(x)$ over the limits $-\infty$ to x.

BERNUI: Computes the geometry of each earthquake source (i.e., area, length) and computes probability distributions for each source.

OUTPUT: Selects the outputs to be listed on the line printer and to be saved on disk for plotting purposes.

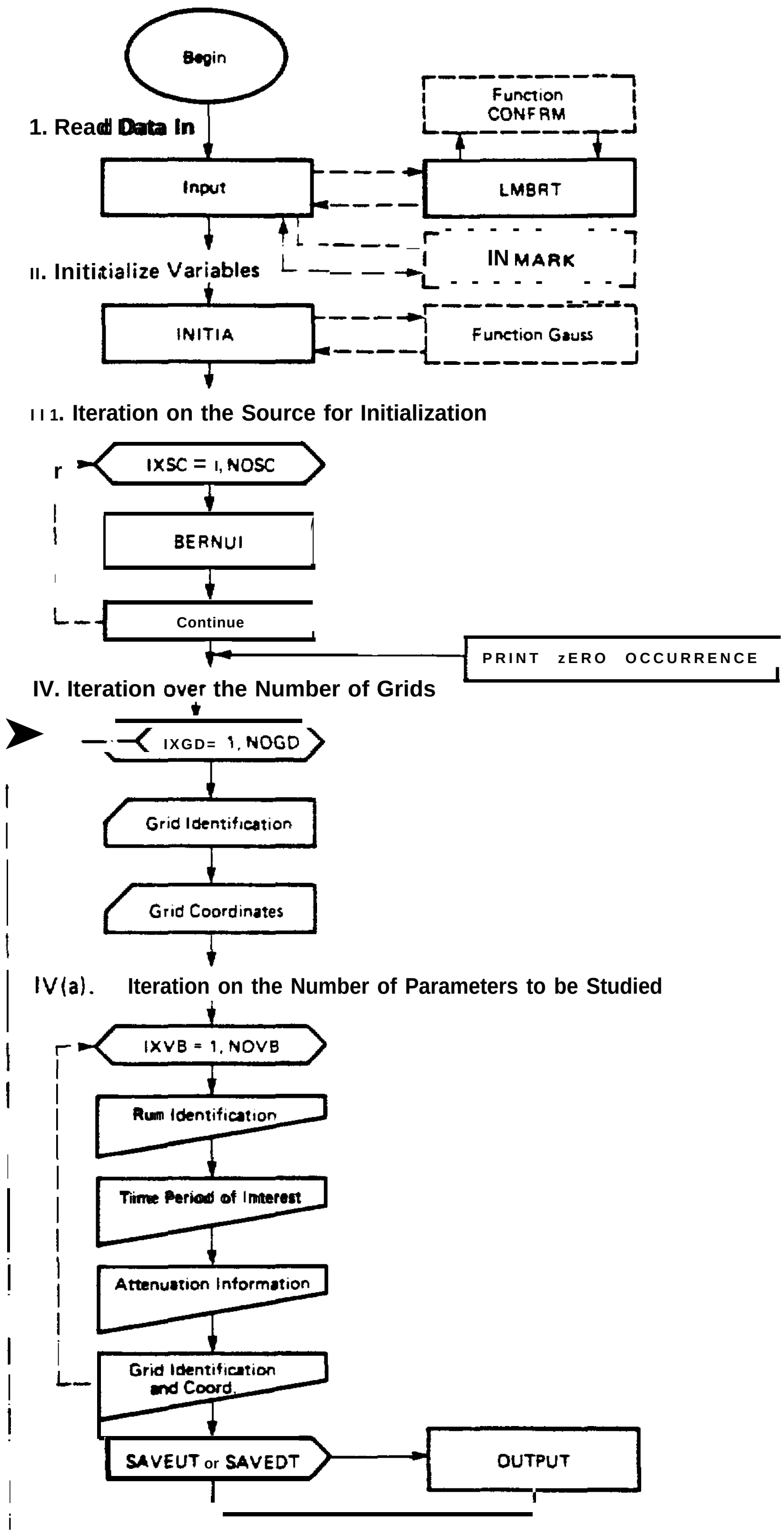


Fig. B-1 - Macro-Flow Chart for the SEISMIC "EXPOSURE Program

INTGAR : Obtains shortest distance from site(s) to area sources. Checks to determine if the perpendicular from site(s) to source falls within or outside the source.

EDGECK : Computes the shortest distance from site(s) to the edges of the earthquake sources.

INTGHZ : Computes the contribution to level of ground-motion parameter at a site from each segment in which a line source has been subdivided. Considers area sources to be composed of a series of line sources subdivided into small segments and computes the contribution of each segment to the level of ground-motion parameter at a site(s).

PBPDF , PWPDF : Computes the contribution of the last segment considered to each ground-motion parameter.

SUMQ : Computes the term P $A \geq a_i$ for each earthquake source.

B.2.0 MARKOV PROGRAM - DESCRIPTION OF SUBROUTINES

The MARKOV program consists of a main program with two subroutines and two functions. These program elements are discussed briefly below. A macro-flow chart of the program is shown in Figure B-2,

MAIN - This program reads the initial seismicity conditions, establishes the arrays needed in producing the final probabilities, and computes the marginal probabilities.

POST - This subroutine reads the observed and prior data, then calculates the means, standard deviations, and degrees of freedom for each Mi and each transition probability, P_{ij}, for input into MAIN.

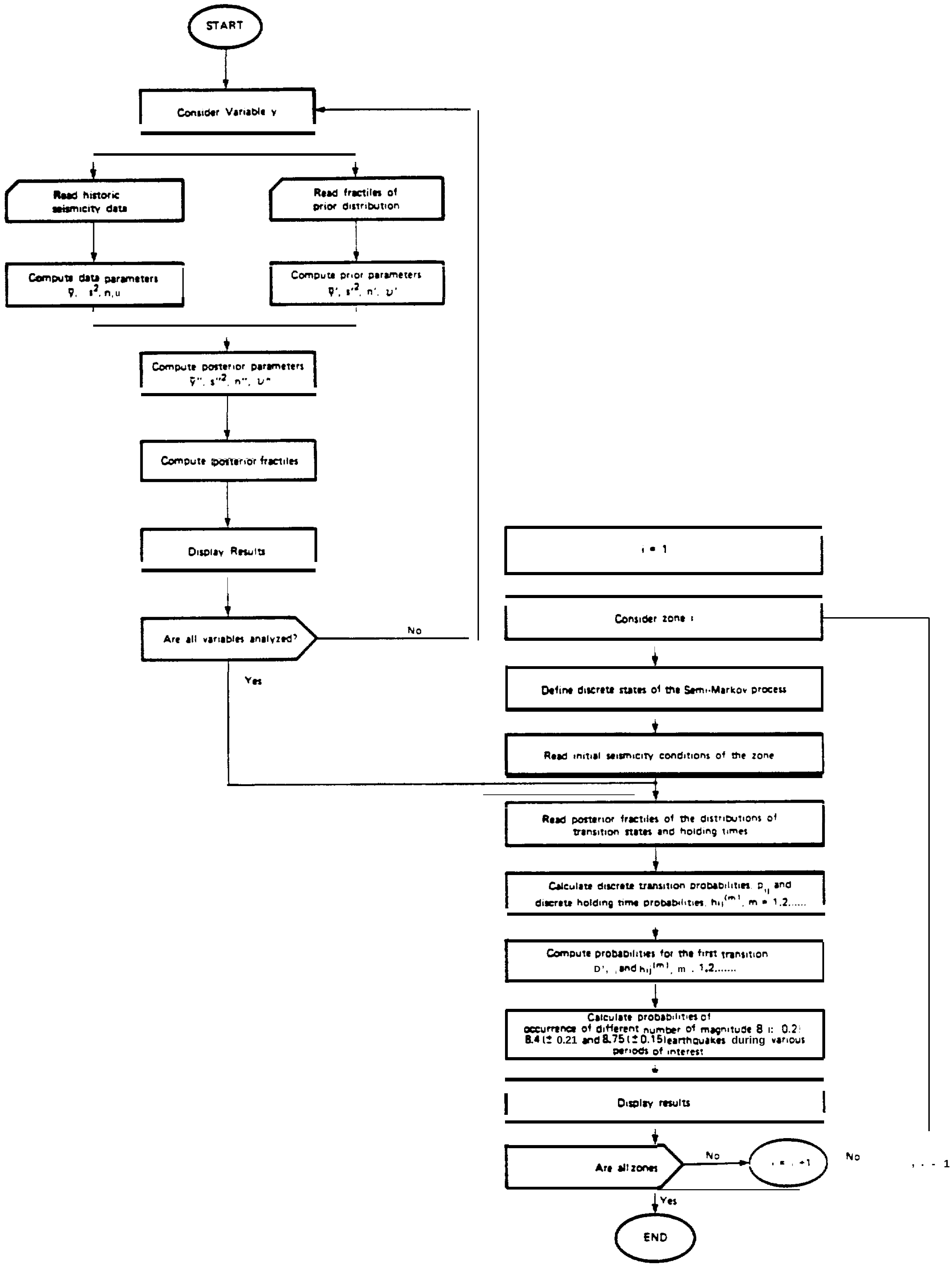


Fig. B-2 – Macro-Flow Chart for Program MAR KOV

INZW - This subroutine initializes the W_i and $w_i(.)$ arrays for the recursive computations of the joint probabilities of state occupancies.

FX - This function calculates the cumulative distribution function of the student-t distribution: given the mean, standard deviation, degrees of freedom, and t-value.

INDEX - This function generates the maximum number of combinations for a given value of NSTATE and of the maximum number of earthquakes. It also calculates the outcome identification number for referencing the Q array.

B.3.0 CONST.PROB PROGRAM

This program must be executed if a seismic exposure map is desired. The macro-flow chart in Figure B-3 shows how the output of the SEISMIC.EXPOSURE program is used as input to CONST.PROB.

B.4.0 PLOT.ISO PROGRAM

This program takes the output from PLOT.ISO, as saved on disk, and computes contours of ground-motion parameters for user-selected levels of exceedance. A macro-flow chart is shown in Figure B-4.

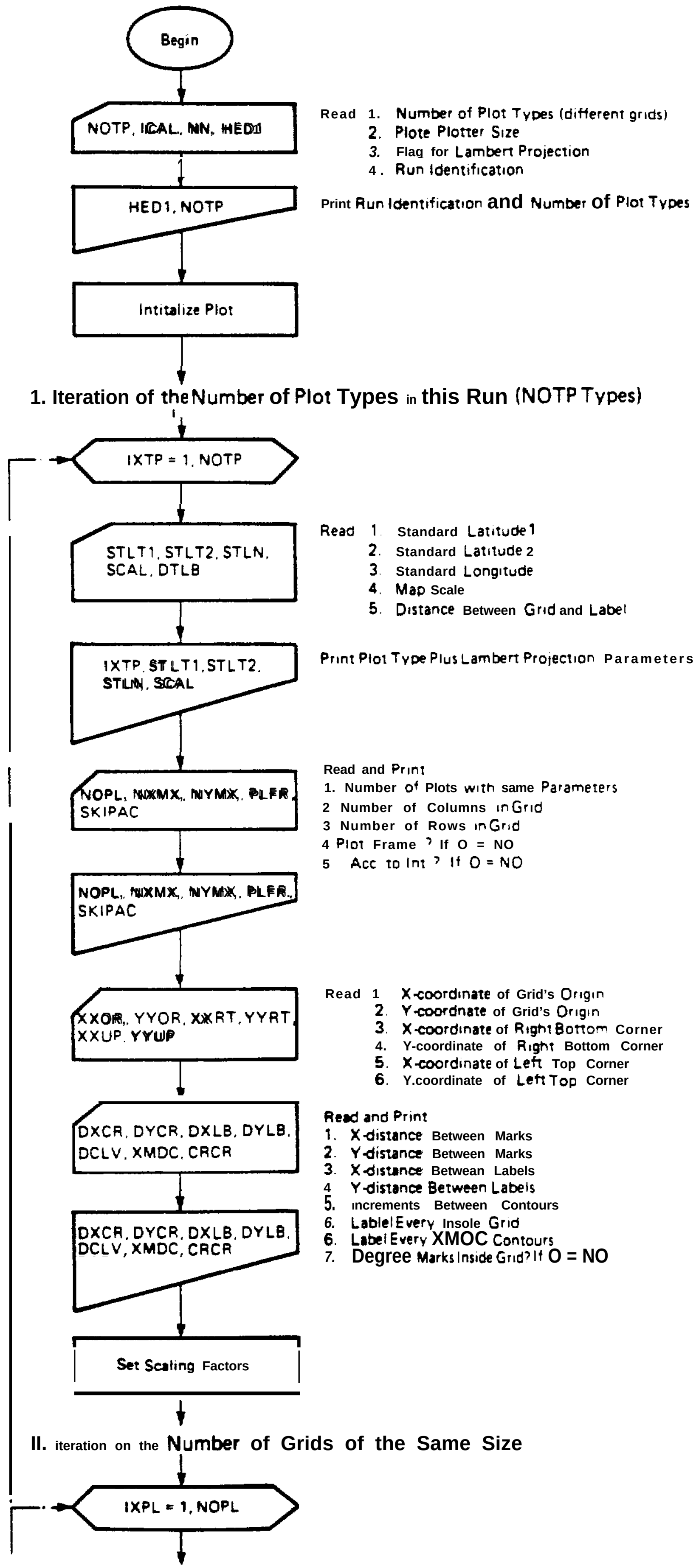


Fig. B-3 - Macro-Flow Chart for Program CONST· PROB

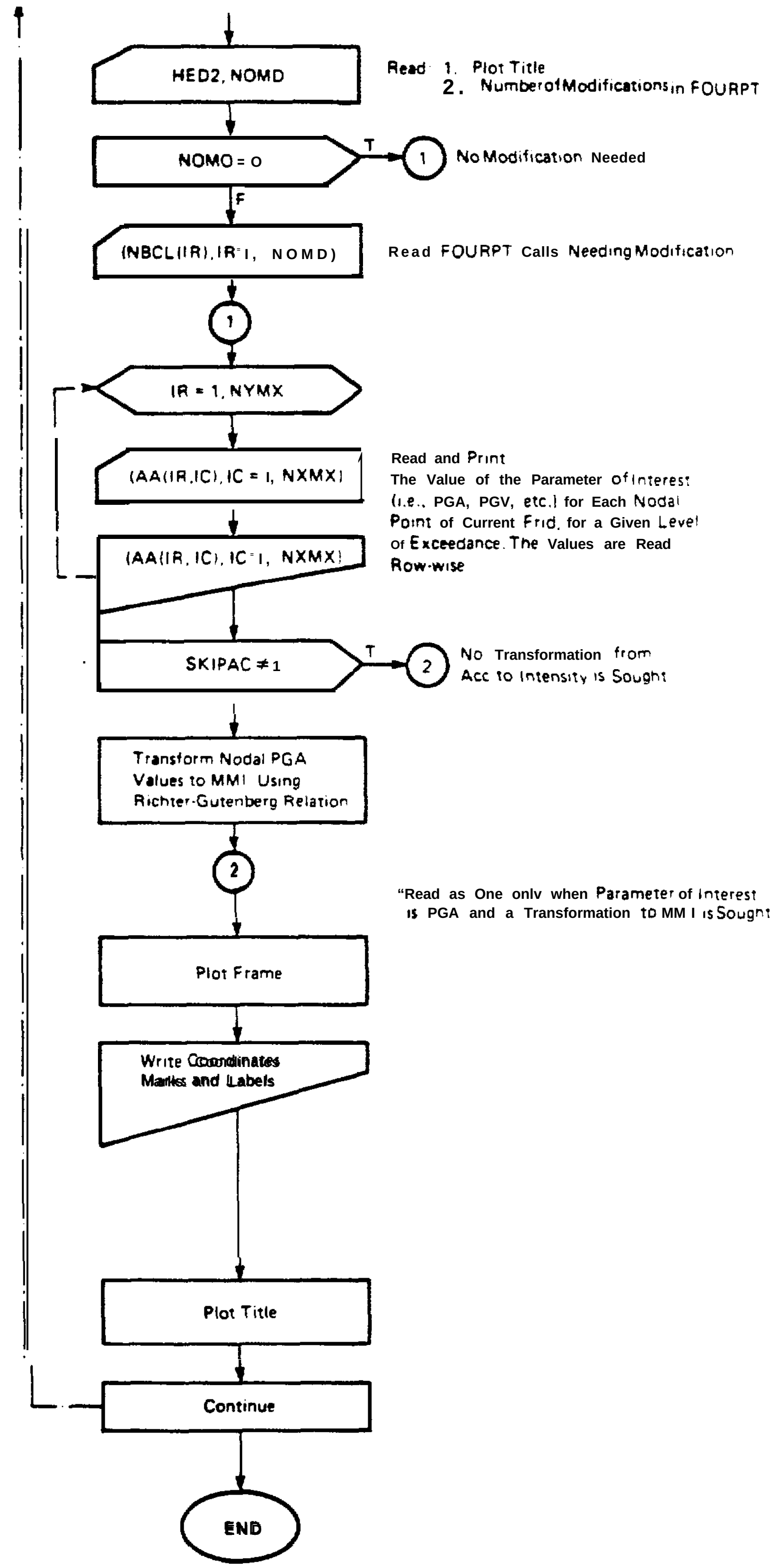


Fig. B-3 - Macro-Flow Chart for Program CONST-PROB (continued)

- Unit = 5 Card Reader and Unit= 6 Line Printer

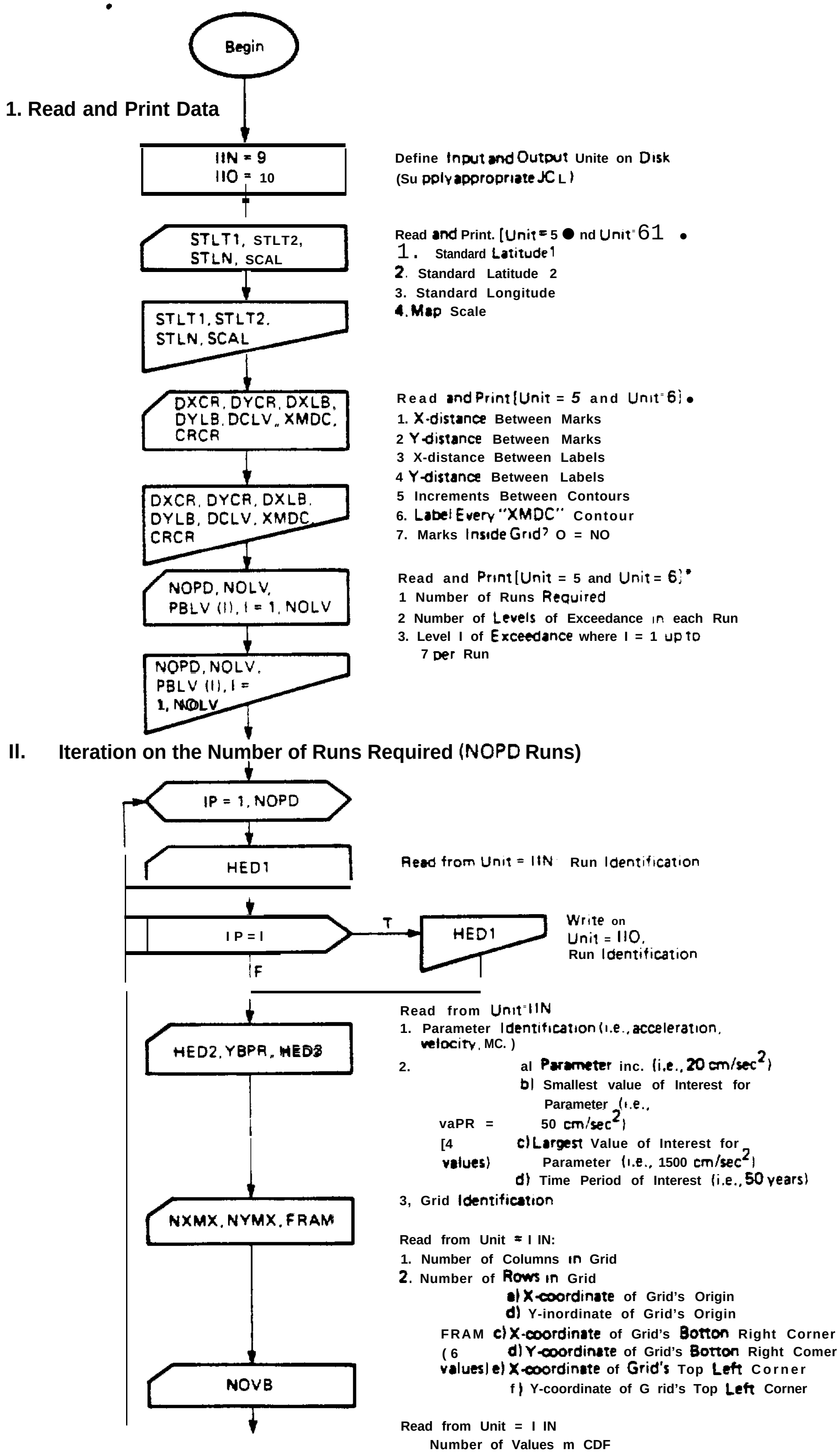
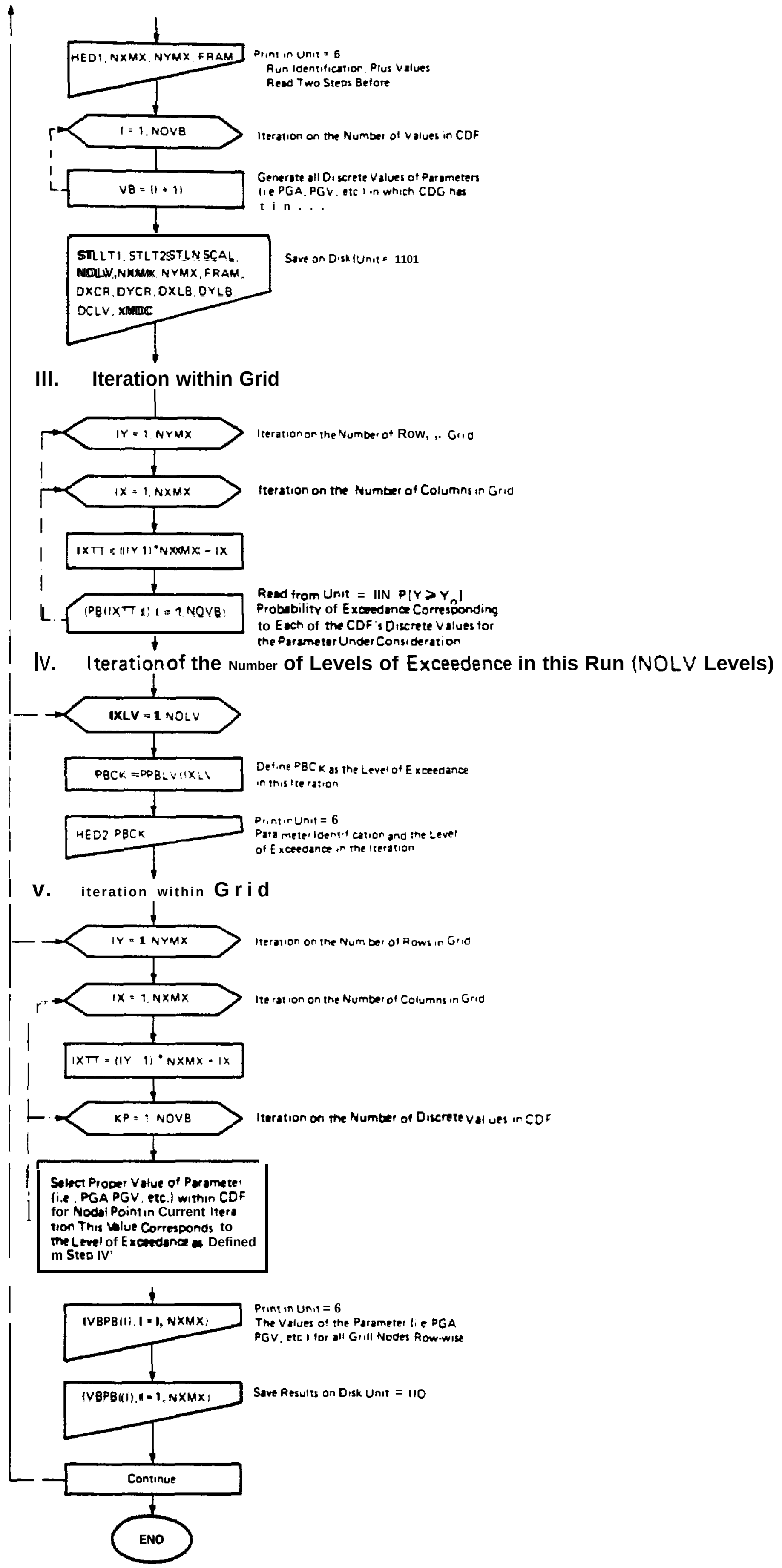


Fig. B-4 - Macro-Flow Chart for Program PLOT-ISO



Fig, B-4 - Macro-Flow Chart for Program PLOT. I SO (continued)

APPENDIX C

ASSESSMENT OF SUBJECTIVE DATA

Since the upper range of holding times between great earthquakes can be a couple of hundred years, the historical seismicity data of about 80 years are generally inadequate to provide reliable estimates of the parameters of a semi-Markov process; namely, transition and holding time probability distributions. To overcome this difficulty, a Bayesian procedure was employed. This procedure utilizes both "objective" (historical seismicity) data as well as "subjective" data based on judgments of qualified individuals and, consequently, improves the reliability of the computed parameters. A summary of objective, subjective, and the combined data is given in the main text. This appendix describes the procedure that was used to assess subjective data.

The concept of subjective (personalistic) probability has a sound theoretical basis. In the mathematical development of the personalistic probability theory, it is shown that subjective probabilities assessed in accordance with certain plausible behavior postulates of coherence must conform mathematically to a proability measure (de Finetti, 1964; Savage, 1954). The techniques for assessing subjective probabilities are well documented and operational (Stael von Holstein, 1970; Winkler, 1967; Raiffa, 1968). These techniques have been applied to a wide variety of practical problems, including weather forecasting (Winkler and Murphy, 1968), estimating fault displacements (Nair and Cluff, 1977), and assessing failure probabilities for nuclear power plants (Selvidge, 1972).

The subjective probability-assessment procedure used in this example consisted of one-on-one interviews with two seismologists. (Please refer to Volume II documentation for details of the subjective probability-assessment procedure used to obtain the initial input for the seismic exposure application to the Gulf of Alaska.) The interviews in this example were structured around the following steps:

Step 1 - Qualitative assessment of relative likelihoods.
Step 2 - Assessment of probabilities.
Step 3 - Feedback and reassessment, if necessary.

Step 1 - Qualitative Assessment of Relative Likelihoods

It was explained to the seismologists that the primary objective of the interview was to quantify their judgments regarding the holding time between earthquakes of given magnitudes and the magnitude of an earthquake following a given-magnitude earthquake. The range of earthquake magnitudes included in the study was 7.8 to 8.8. Since precise values of these variables could not be determined, it was necessary to talk about the likelihoods of different values of the variables.

In the first step, only qualitative statements regarding relative likelihoods and various events were sought. This involved comparing two or more events and indicating which seemed more (or less) likely to occur. No numerical values or probabilities were yet assessed. This step provided a relative understanding of the amount of uncertainty that is perceived by the experts. The discussion generated during this step can be summarized as follows:

1. An earthquake of magnitude 8 ($\pm$ 0.2) was judged much more likely to occur following any other great earthquake.

2. If a great earthquake is not followed by an 8(± 0.2)-magnitude earthquake, the next great earthquake is somewhat more likely to be of magnitude 8.4(± 0.2) than of magnitude 8.75 (± 0.15).

3. The likelihood of occurrence of a given-magnitude earthquake was insensitive to the magnitude of the last earthquake.

4. Generally, 8 (± 0.2)-magnitude earthquakes occur more frequently than do 8.4(± 0.2) ones.

5. The 8.75(± 0.2)-magnitude earthquakes occur much less frequently than either the 8(± 0.2)- or 8.4(± 0.2)-magnitude earthquakes.

6. The holding time to a given-magnitude great earthquake is relatively insensitive to the magnitude of the last great earthquake.

<u>Step 2 - Quantitative Assessment of Probabilities</u>

In this step, numerical values of probabilities were assessed. The transition states and the holding times were considered to be continuous random variables, and the cumulative distribution function (CDF) of each was obtained by using the fractile method discussed in the literature (see, for example, Raiffa, 1968). This method consists of successively dividing a given range of a random variable into equally likely parts. To illustrate this procedure, consider the assessment of CDF of: (1) the earthquake magnitude, M_1, following an 8(± 0.2)-magnitude earthquake; and (2) the holding time, T_{11}, between two successive earthquakes of magnitude 8(± 0.2).

(1) Assessment of CDF of M_1 - The range of Ml was 7.8 to 8.8. This assumed that the zone of interest had the potential for generating a maximum earthquake of magnitude 8.8. The experts were asked the following question:

> "Suppose an 8-magnitude earthquake has just occurred in a zone. Is the magnitude of the next great earthquake in the same zone more likely to be in the range 7.8 to 8.6 or greater than 8.6?"

To strengthen the understanding of the above question, the relative frequency content was also posed as follows:

> "Suppose that earthquake records over a long period of time are available. We identify all the instances in which an 8-magnitude earthquake was followed by another great earthquake. Do you think more of these earthquakes following the 8-magnitude earthquake wouldbeinthe magnitude range 7.8 to 8.6 or 8.6 to 8.8?"

The response of the seismologists to these questions indicated that a great earthquake following an 8-magnitude earthquake is more likely to be of magnitude 7.8 to 8.6 than of magnitude greater than 8.6. Next, it was asked whether the magnitude of the next great earthquake was more likely to be between 7.8 and 7.9 or greater than 7.9. An earthquake of magnitude greater than 7.9 was judged more likely to occur. By systematically varying the division of the magnitude range 7.8 to 8.8, a point was selected so that the magnitude of the next great earthquake was equally likely to be on either side of this point. This is the 0.50 probability point (say, $M_1^{0.50}$) on the CDF of M_1.

Next, the ranges of 7.8 to $M_1^{0.50}$ and $M_1^{0.50}$ to 8.8 were divided into equally likely parts to yield $M_1^{0.25}$ and $M_1^{0.75}$

points, respectively, on the CDF of M_1. A smooth curve was drawn for the CDF of M_1 through the three assessed points ($M_1^{0.25}$, $M_1^{0.50}$, and $M_1^{0.75}$) and two end points (7.8 and 8.8).

Several consistency checks, which are discussed in the literature (see, for example, Schlaifer, 1954), were applied to ascertain whether the responses of the seismologists were coherent. For example, one of the consistency checks was to ask the seismologist to bet on one of the two options:

Option 1 - Magnitude of the great earthquake which follows an 8-magnitude earthquake is in the range $M_1^{0.25}$ and $M_1^{0.75}$.

Option 2 - Magnitude of the great earthquake which follows an 8-magnitude earthquake is outside the above range on either side.

If the previous assessments are reasonable, the seismologists should have little preference between the two options. If he prefers one option to another, this would indicate an inconsistency with respect to one or more of the previous assessments. In such a case, the implication of the inconsistency was discussed with the assessor, and some (or all) of the previous questions were repeated until consistency was achievea. The consistency checks were extremely useful since they generally forced the assessor to think harder about the physical phenomenon and also to utilize all the information available to him in responding to the questions.

(2) <u>Assessment of CDF of T_{11}</u> - The holding time probability distribution refers to the likelihood that the time in between great earthquakes of given magnitudes is less than or equal to a given value. The fractile method discussed in the previous sections was used in assessing the CDF of T_{11}. First, the

upper limit of $_{11}$ was established by asking about the maximum time which could elapse between two successive 8($\pm$ 0.2)-magnitude earthquakes. Then the three fractiles (0.25, 0.50, and 0.75) were assessed. A smooth CDF curve was drawn through three fractile points and the two end points. Again, consistency checks were applied to ascertain coherent responses.

Step 3 - Feedback and Reassessment

Steps 1 and 2 were completed during a half-day session. The next day, a joint session with the experts was arranged. The CDF curves for all the variables were shown, and the implications of the results were discussed. Any significant discrepancies between the experts were also discussed. The group discussion was extremely helpful with regard to exchange of ideas and information pertinent to the assessment of transition states and holding times between occurrences of great earthquakes. The results were also examined to check whether they were consistent with the qualitative judgments expresses in Step 1. For example, fractiles of T_{11} were lower than the corresponding fractiles of T_{12}, which in turn were lower than those of T_{13}. This was consistent with the judgment that 8($\pm$ 0.2)-magnitude earthquakes occur more frequently than either 8.4($\pm$ 0.2)- or 8.75($\pm$ 0.15)-magnitude earthquakes.

The feedback session resulted in some modifications in the initial assessments. It was possible to establish a base case of subjective assessments for which both the experts were in agreement. The base case was used in the Bayesian analysis.

APPENDIX D

SOFTWARE SYSTEMS INFORMATION

Documentation of the project work is available as two volumes of printed documents and in the form of a computer magnetic data tape. This appendix describes the format of the data and the contents of the data tape. To facilitate program execution on computers other than the Univac 1108, which was used to develop the software, selected modifications to the variables are also discussed.

D.1.0 DATA TAPE

Each of the source programs, data elements, and absolute elements required for program execution are written as separate files with an end-of-file mark. The tape has 9-tracks and 80-character record lengths with a blocking factor of 45; it is a 1600-bpi ASCII, non-labelled, odd parity tape. Print files have 132-character record lengths.

The files are listed below in the order in which they appear on the tape.

Program Files

- SEISMIC.EXPOSURE
- MARKOV .
- CONST.PROB
- PLOT.ISO
- NODEX (NODEX is a plotting program that can be used to check SEISMIC.EXPOSURE input geometry)

Sample Problem

- SAMPLE 1. - non-semi-Markov seismic-exposure problem input
- SAMPLE 2. - semi-Markov seismic-exposure problem input
- SAMPLE 2A. - semi-Markov MARKOV input

OUTPUT FILES

- MARKOV (print)
- MARKOV (disk)
- EXPOSURE 1 (print)
- EXPOSURE 1 (disk)
- EXPOSURE 2 (print)
- CONST.PROB 1 (disk)

D.2.O PROGRAM MODIFICATIONS

The SEISMIC.EXPOSURE program is presently dimensioned for 50 sources and requires 150k for program execution with 44 sources, three ground-motion parameters, and 96 grid points (sites). The chief factor affecting core-size requirements is the choice of the maximum number of sources. To reduce the program size, certain variables need to be re-set. These and other variable changes are discussed below

To change the number of sources from 50 to (?), change the common statements in the subroutines:

MAIN, INPUT, INTGAR, INTGHZ, BERNUI, SUMQ, INITIA, SUNQ, PBPDF, PWPDF, INMARK, PRINT, PRINT2, and OUTPUT

Change:

```
COMMON/INTGD1/NBEGSC ( ), NBHRSC ( ), NBVTSC ( )

COMMON/SOURCI/ . . . . . . . . . . . . . .
COMMON/BRNUI/. . . . . . . . . . . . . . ., PSOR (? + 1)
COMMON/ACVR/ . . . . . . . . . . . . . . .
COMMON/PTABLE/ . . . . . . . . . . . . . .
```

Also make changes in:

Subroutine	Variable Name
MAIN	HOLD (13,50) HOLD (18,?) DATA HOLD/A*0.0/A = 18 x?
BERNUI	COMMON/PSNMG/INDEX (?)
PRINT	A (18,?), COLSUM (?), ROWSUM (?), ISORCE (?)
PRINT2	SUMSOR (?), ISOURCE (?), SORTYP (?)

To change the number of attenuation relations:

COMMON/ATTENR/
COMMON/ATTEN 1/
COMMON/PTABLE/

To change the number of nodes:

COMMON/SIDES/

To change the number of segments:

COMMON/SIDES/

To change the number of elements:

COMMON/SOURCI /

To change the SEISMIC.EXPOSURE program so that it doesn't print tables, change CPESM(1) in PRINT, and PRINT2 (check..?).

D.3.0 PROGRAM ADAPTATION

Users of VAX Fortran should be aware that their systems will not properly handle the entry points in SEISMIC.EXPOSURE and PLOT.ISO. Entry point INTGLN into subroutine INTGHZ is called by MAIN in SEISMIC.EXPOSURE. Both PLOT.ISO and SEISMIC. EXPOSURE call initialization entry points in the projection subroutines (MRCTR and LMBRT). We recommend that these entry points be eliminated, either through the use of IF statements or by separation into two subroutines.

SEISMIC.EXPOSURE calls DLGAMA (double precision log of the gamma function). This option is not available on all systems.

MARKOV Program

The semi-MARKOV program is presently configured for a three-state system (three magnitude intervals) with a 5-year time interval and a 10.0 M_w maximum magnitude.

To modify these parameters, references to "10.0" need to be changed to "the desired maximum magnitude value" in MAIN and subroutine POST. The 5-year time interval can be modified by changing the dimensions of array H in MAIN and in subroutine INZW from 100 to the desired dimension. The dimension is calculated on the basis of the following expression:

T = desired time interval in years

FCAST = number of years forward

$$\text{H array dimension} = \frac{\text{largest holding time in years (e.g., 1000 years)} + \text{FCAST} + \text{T}}{\text{T}}$$

Also, array HGT in subroutine INZW needs to be dimensioned at

$$\frac{\text{largest holding time} + T}{T}$$

instead of 201.

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Fig. 40 – Output from Program SEISMIC" EXPOSUR E using Input from Program MARKOV (Sample Problem 2) as obtained on Line Printer

```
SAMPLE SEISMIC EXPOSURE MAPS  -  APRIL 1982
MARKOV INPUT USED

PLOTTER SIZE                      30
PLOT PROJECTION                    1
STANDARD LATITUDE 1               35.0000
STANDARD LATITUDE ?               67.00?0
STANDARD LONGITUDE              -153.0000
SCALING FACTOR                2500000.
NUMBER OF AREA SOURCES             4
NUMBER OF LINE SOURCES             1
NUMBER OF NODES                   16
NUMBER OF ELEMENTS                 4
NUMBER OF GRIDS                    1
NUMBER OF VARIABLES                1
NUMBER OF ATT/VARIABLE             2
LINES PRINTED PER SITE             5
MAX NO. Of MAG                     9

SAVE RESULTS ON DISK (PLOTTING FORMAT)    5 0  VALUES PER SITE


TIME PERIOD   MAG INC    SMALLEST MAG
   40.00        ●50          5.05
```

NODAL COORDINATES (1 6 NODES)

NODAL INDEX	WCC INDEX	X COORD	Y COORD	7 (KM)	X (KM)	Y (KM)
1	1	-161.890	54.380	-40.000	103.805	243.687
2	2	-160.000	52.1150	-?0.000	295.709	67.559
3	3	-158.480	55.700	-40.000	326.902	363.361
•	4	-156.440	54.200	-20.000	● *?.R3*	195.577
5	5	-156.120	53.960	-20.000	461.833	168.959
6	6	-153.290	55.550	-20.000	641.309	313.912
7	?	-155.770	57.030	-40.000	496.476	● 9?.591
8	8	-192.000	58.R1O	-40.000	710.637	686.805
9	9	-147.700	57.220	-20.000	963.772	525.870
10	10	-146.410	58.900	-20.000	1027.184	712.862
11	11	-150.070	61.630	-40.000	811.000	995.535
12	12	-148.460	57.530	-20.000	922.053	556.544
13	13	-158.000	60.?00	-5.000	389.231	846.243
14	14	-154.000	60.700	-5.000	605.792	891.636
15	15	-152.500	60.700	-5.000	685.683	891.362
16	16	-151.000	61.000	-5.000	764.668	925.331

ELEMENTS DESCRIPTION (4 ELEMENTS)

INDEX	I	J	K	L	RENUMBERED	I	J	K	L
1	4	3	1	2		4	3	1	2
2	6	7	3	5		6	1	3	5
3	12	8	7	6		12	8	7	6
4	10	11	8	9		10	11	8	9

```
AREA SOURCE    1
--------  --------

SAMPLE SOURCE 1
NUMBER OF BANDS 1   BOUNDARY COND    1   1   0   0   ELEMENTS   !  THRU   1
NUMBER OF ELEMENTS IN EACH BAND STARTING WITH DEEPEST ONE     1
TIME DATA BASE . . . . . . . . . . . . . .    75.000
NO OF Occ . . . . . . . . . . . . . . . . .   22.739
NO OF POISSON MAG. . . . . . . . . .           6
```

Fig. 40 – Output from Program SEISMIC" EXPOSURE using Input from Program MARKOV (Sample Problem 2) as obtained on Line Printer (continued)

SUM OF POISSON OCC.......... 2?. 799
DISTRIBUTION OF MAG.

5.050	5.550	6.050	6.550	7.050	7.550
13.739	5.457	2.183	.851	.519	.146

THERE IS No SEMI-MARKOV INPUT FOR THIS SOURCE

AREA SOURCE 2
-------- --------

SAMPLE SOURCE 2
NUMBER Of BANDS 1 BOUNDARY COND 1 1 1 0 ELEMENTS 2 THRU 2
NUMBER OF ELEMENTS IN EACH BAND STARTING WITH DEEPEST ONE 1
TIME DATA Base 75.000
NO OF Occ . . ...*..**...**. . . 56.546
NO OF POISSON MAG.......... 6
SUM OF POISSON OCC......... 46.436
DISTRIBUTION OF MAG.

5.050	5.550	6.050	6.550	7.050	7.550
34.090	3.431	5.416	2.111	1.274	.114

THE NEXT 3 MAGNITUDES ARE SEMI-MARKOV. INPUT IS READ FROM UNIT 17
FILED INFORMATION -
IDKEY......................SAMPLESOURC
NUMBER OF MAGNITUDES 3
MAGNITUDE INCREMENT .... .5000
FIRST S-M MAGNITUDE 8.0500
PERIOD OF INTEREST 40.00

NUMBER OF EARTHQUAKES

DISCRETE MAGNITUDE	0	1	2	3	4	5	6	7	8
8.050	.8700585	.0719999	.0311855	.0121350	.0041888	.0012538	.0003123	.0000595	.0000069
8.550	.9318633	.0547676	.0110829	.0019482	.0002957	.0000380	.0000040	.0000003	
9.050	.9758666	.0240347	.0000906	.0000002					

Markov Input

AREA SOURCE 3
....

SAMPLE SOURCE 3
NUMBER OF BANDS 1 BOUNDARY COND 1 1 1 1 ELEMENTS 3 THRU 3
NUMBER OF ELEMENTS IN EACH BAND STARTING WITH DEEPEST ONE 1
TIME DATA BASE 75.000
NO OF OCC 55.588
NO OF POISSON MAG.......... 6
SUM OF POISSON OCC......... 55.587
DISTRIBUTION OF MAG.

5.050	5.550	6.050	6.550	7.050	7.550
33.512	13.311	5.324	2.075	1.253	.112

THE NEXT 3 MAGNITUDES ARE SEMI-MARKOV. INPUT IS READ FROM UNIT 17
FILED INFORMATION -
IDKEY.....................SAMPLESOURC
NUMBER OF MAGNITUDES 3
MAGNITUDE INCREMENT .... .5000
FIRST S-M MAGNITUDE 8.0500
PERIOD OF INTEREST 40.00

NUMBER OF EARTHQUAKES

DISCRETE MAGNITUDE	0	1	2	3	4	5	6	7	8
8.050	.8228836	.1951228	.0456769	.0177676	.0061375	.0018362	.0004577	.0000875	.0000102
8.550	.8965574	.0680819	.0161281	.0026962	.0003903	.0000480	.0000048	.0000004	
9.050	.9679829	.0318076	.0001194	.0000002					

Fig. 40 – Output from Program SEISMIC EXPOSURE using Input from Program MARKOV (Sample Problem 2) as obtained on Line Printer (continued)

AREA SOURCE 4

SAMPLE SOURCE 4
NUMBER OF BANDS 1 BOUNDARY CONDITION 1 1 1 0 ELEMENTS 4 THRU 4
NUMBER OF ELEMENTS IN EACH BAND STARTING WITH DEEPEST ONE 1
TIME DATA BASE 75.000
NO OF OCC 81.677
NO OF POISSON MAG. 6
SUM OF POISSON OCC. 81.678
DISTRIBUTION OF MAG.

5.050	5.550	6.050	6.550	7.050	7.550
49.241	19.559	7.823	3.049	1.841	.165

THE NEXT 3 MAGNITUDES ARE SEMI-MARKOV. INPUT IS READ FROM UNIT 17
FILED INFORMATION -
IDKEY .SAMPLE SOURC
NUMBER OF MAGNITUDES 3
MAGNITUDE INCREMENT 5000
FIRST S-M MAGNITUDE 8.0500
PERIOD OF INTEREST 40.00

DISCRETE MAGNITUDE	NUMBER OF EARTHQUAKES 0	1	2	3	4	5	6	7	8
0.050	.9390654	.0556775	.0158150	.0063059	.0022332	.0006872	.0001766	.0000359	.0000043
8.550	.9705281	.0248979	.0039337	.0005607	.0001710	.0000078	.0000007		
9.050	.9922402	.0077404	.0000194						

LINE SOURCE 1

SAMPLE LINE SOURCE 1
3 SEGMENTS BOUNDARY CONDITION 0 0 STARTING AT NODE 13 RENUMBERED 13
TIME DATA BASE 75.000
NO OF OCC 247.500
NO OF POISSON MAG. 7
SUM OF POISSON OCC. 295.970
DISTRIBUTION OF MAG.

5.050	5.550	6.050	6.550	7.050	7.550	8.050
174.980	72.530	32.480	12.530	.225	2.025	1.200

THERE IS NO SEMI-MARKOV INPUT FOR THIS SOURCE

ATTENUATION RELATIONSHIPS

ACCEL CM/SEC/SEC IC= 40.000 MN= 100.000 MX= 1500.000

B1	B2	B3	B4	LN SIG	MG MX
198.670	.823	.000	1.561	.568	.000
210.000	.500	.000	.850	.606	.000

C1 .864
C2 .465
DEPTH -6.000

LOG-NORMAL DISTRIBUTION ON ATTENUATION
NO OF SIG ON EACH SIDE OF MEAN 3.0
NO OF INCREMENTS IN DIST 85

INTG. STEP VERT. (KM) 15.000
INTG. STEP HOR. (KM) 15.000
EPSILON (KM) .100

Fig. 40- Output from Program SEISMIC" EXPOSURE using Input from Program MAR KOV (Sample Problem 2) as obtained on Line Printer (continued)

SOURCE/MAGNITUDE CON TQ1OUTIOM TABLEINFORMATION

INPUT SPECIFIES TABLES ARE TO BE GENERATED FOR EVERY 3 INCREMENTS UP TO INCREMENT 10 FOR THESE PARAMETERS -
1

PARAMETER TABLE SIZE (SUM O F MAGNITUDES ACROSS ALL SOURCES) = 40

PARAMETER	MINIMUM	MAXIMUM	INCREMENT	FIRST TABLE	LAST TABLE	FIRST LEVEL	LAST LEVEL	ADDRESS
1	100.000	1500.000	40.000	120.000	600.000	4	16	

TABLE SPACE AVAILABLE - 10800
TABLE SPACE USLO - 200

HORIZONTAL RUPTURE LENGTHS (KM)

5.050	5.550	6.050	6.550	7.050	7.550	8.050	8.550	9.050
2.700	4.700	8.400	15.300	27.000	47.000	91.000	185.000	225.[illegible]

DOWN DIP RUPTURE LENGTHS (KM)

5.050	5.550	6.050	6.550	7.050	7.550	8.050	8.550	9.050
2.700	4.700	8.400	15.000	27.000	47.000	59.000	70.000	80.000

THE CONSTANT c = c1 . EXP(C2*M) IN ATTENUATION FoLIATION

8.9378	11.264	14.195	17.889	22.545	28.412	35.805	44.091	44.091

PARAMETER 1 - ACCEL CM/SEC/SEC

ATTENUATION COEFFICIENT B1. EXP(B2 * M)

9.4082	9.8199	10.232	10.643	11.055	11.467	11.878	12.249	12.249

ATTENUATION COEFFICIENTB1. EXP(B2 . M)

1.8721	8.1221	8.3721	8.6221	8.8721	9.1?71	9.3721	9.5971	9.5971

*** SOURCE GEOMETRY WARNINGS FOR AREA SOURCE 1
SOURCE DIMENSIONS - LEFT 205.4 RIGHT 204.5 DOWN-DIP LENGTH 204.2
WIDTH OF EACH LEVEL FROM BOTTOM TO TOP
1 253.5
2 269.5
BOUNDARY CONDITION +1 IS IN EFFECT FOR TOP OF SOURCE.

*** SOURCE GEOMETRY WARNINGS FOR AREA SOURCE 2
SOURCE DIMENSIONS-LEFT 234.8 RIGHT 238.0 DOWN-DIP LENGTH 234.7
WIDTH OF EACH LEVEL FROM BOTTOM TO TOP
1 215.9
2 230.7
BOUNDARY CONDITION ● I IS IN EFFECT FoR ToP OF SOURCE.
MAGNITUDE 9005 RUPTURE DIMENSIONS - HORIZONTAL 225.0 DOWN-DIP 75.0
HORIZONTAL OR DOWN-DIP LENGTH OF SOURCE IS BELOW RECOMMENDED LIMIT FOR GIVEN BOUNDARY CONDITIONS AND RUPTURE DIMENSIONS.

*** SOURCE GEOMETRY WARNINGS FOR AREA SOURCE 3
SOURCE DIMENSIONS - LEFT 249.1 RIGHT 234.8 DOWN-DIP LENGTH 234.5
WIDTH OF EACH LEVEL FROM BOTTOM TO TOP
1 285.8
z 371.1
BOUNDARY CONDITION +1 1S IN EFFECT FOR TOP OF SOURCE.

*** SOURCE GEOMETRY WARNINGS FOR AREA SOURCE 4
SOURCE DIMENSIONS - LEFT 3[illegible] RIGHT 300.6 DOWN-DIP LENGTH 2[illegible]
WIDTH OF EACH LEVEL FROM BOTTOM TO TOP
1 [illegible]

Fig. 40 – Output from Program SEISMIC" EXPOSURE using Input from Program MARKOV (Sample Problem 2) as obtained on Line Printer (continued)

```
 2     197.5
BOUNDARY CONDITION 1 IS IN EFFECT FOR TOP OF SOURCE.
MAGNITUDE 9.05          RUPTURE DIMENSIONS - HORIZONTAL    225.0      DOWN-DIP    75.0
HORIZONTAL OR DOWN-DIP LENGTH OF SOURCE IS BELOW RECOMMENDED LIMIT FOR GIVEN BOUNDARY CONDITIONS AND RUPTURE DIMENSIONS.
```

PROBABILITY OF ZERO OCCURRANCE PER INCREMENT PART 1

MAG	AREA SOURCE 1	AREA SOURCE 2	AREA SOURCE 3	AREA SOURCE 4	LINE SOURCE 1
5.05	.973669	.923017	[illegible]	.934883	.772699
5.55	.988614	[illegible]	.989738	.971430	.310077
6.05	.995275	.98554	.991579	.988067	.582019
6.55	.998129	.994239	.996820	.995263	.804762
7.05	.999866	.996553	.998171	.997126	.996156
7.55	.999898	.999684	.999426	.999741	.965986
8.05	.000000	[illegible]	.999483	.999829	.979688
8.55	.000000	.999708	.999698	.999913	.000000
9.05	.002000	.995896	.999916	.999977	.000000

Fig. 41 – Diskfile Output Saved from Program SEISMIC· EXPOSURE using Results from Program MARKOV (Sample Problem 2) as obtained on Line Printer

● ≈≈x≈≈ P R O B A B I L I T Y O F A T L E A S T O N E E X C E E D E N C E I N 40.00 Y E A R S ● *****

SAMPLE SEISMIC EXPOSURE MAPS - APR 11 1982
MARKOV INPUT USED
SEISMIC EXPOSURE MAP GROUND MOTION VALUES - SAMPLE PROBLEM

A C C E L c M/s E c / S [c

INC = 40.000
MIN = 100.000
MAX = 1500.000

SITE COORDINATES X,Y,Z -156.000 58.000 .000 487.285 602.557

.00000	40.03000	80.03000	120.00000	160.00600	200.00000	240.00000	280.00000	320.00000	360.00000
1.00000	1.00000	.99996	.92996	.59733	● 35599	.18464	.10121	.06247	.03751
.00	.00	.00	15.55	44.48	91.40	196.46	375.36	620.59	1046.88
400.00000	440.00000	480.00000	520.06000	560.00000	600.00C00	640.00000	680.00000	720.00000	760.00000
.02198	.01520	.01039	.0.699	.00463	.0 [,300	.00239	.00189	.00116	.00091
1000.50	2612.43	3829.37	5704.35	8616.36	13329.34	16743.86	21160.52	34323.02	.00
800.00000	840.00000	080.00000	920.30000	960.00000	10UO.OO[OO	1040.00000	1080.00000	1120.00000	1160.90000
.00069	.00040	.00050	.00022	.00016	.00010	.00008	.00007	● ooon5	.00003
●00	.00	●00	.00	.00	.00	.00	.00	.00	.00
1200.00000	1240.00000	1280.00000	1320.00000	1360.00000	1400.00000	1440.00000	480.00000	1520.00000	156,0.00000
.00002	.00001	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.017000
.00	●00	.00	.00	.00	.00	.00	.00	.00	.00

PARAMETER 1 ACCEL CM/SEC/SEC = 120.00 MAGNITUDE/SOURCE PERCENTAGE CONTRIBUTION TABLE PART 1

MAG	AREA SOURCE 1	AREA SOURCE 2	AREA SOURCE 3	AREA SOURCE 4	LINE SOURCE 1	ROWSUMS
5.05	.1365	8.4871	12.2650	.9407	.0000	21.9293
5.55	.3748	2.1571	11.1503	1.9010	.0000	15.5832
6.05	.4853	7.5948	8.9843	2.2098	.0000	19.2742
6.55	.4717	5.4255	6.3910	2.1591	.0000	14.4472
7.05	.6635	6.0074	6.2961	2.8456	.0000	15.8126
7.55	.1122	.7782	.8477	.4920	.0000	2.2300
8.05	.0000	1*7945	4.2013	.8119	.0315	6.8392
8.55	.0000	.0000	2.6551	.4512	.0000	3.1063
9.05	.0000	.0000	.7702	.1078	.0000	.8781
SUMS	2.2439	32.2445	53.5610	11.9190	.0315	.26586+001

Fig. 41 – Diskfile Output Saved from program SEISMIC.EXPOSURE using Results from Program MARKOV (Sample Problem 2) as obtained on Line Printer (continued)

PARAMETER 1 ACCEL CM/SEC/SEC = 240.00 MAGNITUDE/SOURCE PERCENTAGE CONTRIBUTION TABLE PART 1

MAG	AREA SOURCE 1	AREA SOURCE 2	AREA SOURCE 3	AREA SOURCE 4	LINE SOURCE 1	ROWSUMS
5.05	.0000	.8254	3.5613	.0003	.0000	4.3467
5.55	.0000	.6037	5.7335	.0000	.0000	6.3372
6.65	.0003	4.1823	7.3894	.0937	.0000	11.6654
6.55	.0865	5.0699	7.7933	.5262	.0000	15.4351
7.05	.3701	7.9887	10.5389	1.8289	.0000	20.7267
7.55	.1135	1.5551	1.9902	.4993	.0000	.14QI
8.05	.0000	6.8788	15.51'59	1.3227	.0000	23.7169
8.55	.0000	.0007	11.3672	.9562	.0000	12.3234
9.05	.0000	.0003	3.0441	.2165	.0000	3.2606
SUMS	.5701	27.1030	66.8339	5.4930	.0000	.20412+0)0

PARAMETER 1 ACCEL CM/SEC/SEC = 360.00 MAGNITUDE/SOURCE PERCENTAGE CONTRIBUTION TABLE PART 1

MAG	AREA SOURCE 1	AREA SOURCE 2	AREA SOURCE 3	AREA SOURCE 4	LINE SOURCE 1	ROW SUMS
5.05	.0000	.0000	.0000	.0000	.0000	.0000
5.55	.0300	.0342	1.5797	.0017	.0000	1.6139
6.05	.0300	1.0729	3.8345	.0000	.0000	4.9075
6.55	.0000	2.5792	5.7344	.0000	.0000	8.3136
1.05	.0045	6.4254	10.5402	.2442	.0000	17.214?
1.55	.0647	1.7691	2.6482	.2879	.0000	4.7699
8.05	.0000	10.7527	24.3448	1.1733	.0000	36.3108
8.55	.0000	.0000	20.3198	1.03411	.0000	21.3546
9.09	.0000	..)000	5.2833	.2321	.0000	5.5154
SUMS	.0692	22.6335	74.3249	2.9724	.0000	.38227-001

PARAMETER 1 ACCEL CM/SEC/SEC = 480.00 MAGNITUDE/SOURCE PERCENTAGE CONTRIBUTION TABLE PART 1

MAG	AREA SOURCE 1	AREA SOURCE 2	AREA SOURCE 3	AREA SOURCE 4	LINE SOURCE 1	ROWSUMS
5.05	.0000	.0000	.0000	.0000	.0000	.0000
5.55	.0000	.0000	.0000	.0000	.0000	.0000
6.05	.0000	.0000	.9096	.0000	.0000	.9096
6.55	.0000	.6688	3.3236	.0000	.0000	3.9924
7.05	.0000	3.5114	8.3394	.0000	.0000	11.8508
7.53	.0000	1.6179	2.9475	.0308	.0000	4.5962
8.05	.0000	12.8581	29.5796	.5293	.0000	42.9670
8.55	.0000	.0000	27.5070	.9052	.0000	28.4123
9.05	.0000	.3000	7.0690	.2027	.0000	7.2717
SUMS	.0000	18.6563	79.6757	1.6680	.0000	.10448-001

Fig. 41 – Diskfile Output Saved from Program SEISMIC" E XPOSURE using Results from Program MARKOV (Sample Problem 2) as obtained on Line Printer (continued)

PAR AMETER 1 ACCEL CM/SEC/SEC = 600.00 M AGNITUDE/SOURCE PERC ENTA GE CONTRIBUTION TABLE PART 1

MAG	AREA SOURCE 1	AREA SOURCE 2	AREA SOURCE 3	ARE A SOURCE 4	LINE SOURCE 1	ROWSUMS
9009	.0000	.0000	.0000	.0000	.0900	.0000
5*55	.0000	.0000	.C000	.0000	.0000	.0C00
6.05	● 0000	.0000	.0000	.0000	.0 (00	.C000
6.55	.0000	.0000	.7754	.0000	.0000	.7754
7.05	90000	1.0038	5.3837	.0C00	.0000	6.3874
7.55	.0000	1.0074	?. 8856	.0000	.0000	3.8930
8.05	.0000	13.3723	31.6135	.0399	.0000	● 3.025r
8.55	.0000	.0000	34.5945	.3931	.0000	34.9876
9.05	.0000	.0000	8.8430	.0880	.C000	8.9310
Sums	.0000	15.303s	84.0956	.5209	.0000	.30010-002

PAR AMETER 1 ACCEL CM/SEC/SEC SUMMARY MA GNITUDE/SOURCE CONTRIBUTION TABLE PART 1

VALUE	AREA SOURCE 1	AREA SOURCE 2	AREb SOURCE 3	ARCA SOURCE 4	1 INE SOURCE 1	ROWSUMS
120.0	.59657- 001	.85726.000	.14240+001	● 31688*000	● eYn42-oo3	.26586+001
240.0	.11638- 002	.55323-001	. 13642.000	. 11212-001	.00000	.20412+000
360.0	.26457 -004	.86521 -002	. 28412-001	.11363-)02	.00C00	. 38.727-001
480.0	.00000	. 19492-002	.83243-002	.17427-003	.00000	.10448-001
600.0	900000	.46166-003	.25237-0J2	.15633- 004	.00030	.3 OO1O-OG2

@BK2.N

Fig. 42 – Plotfile Output from Program SEISMIC · EXPOSURE using Results from Program MARKOV (Sample Problem 2) as obtained on Line Printer and saved on Disk

```
    1   30    1
    35,000    67.000   -1.53.000 ?500000 .       .000
     1.000     1.000     1.000     1.000    20.000      2.000      1.000
SAMPLE SEISMIC EXPOSURE MAPS  -  APRIL 1982
MARKOV INPUT USED
ACCEL    CM/SEC/SEC        40! 000    100.000  1500.000     40.000
SEISMIC EXPOSURE MAP GROUND MOTION VALUES - SAMPLE PROBLEM
  -156.000     58.000      .000       .000       ,000       ,000
    1    1    0    0
        40
 1.00000 1.00000  .99996  .92996  ,59733  .35599  .18464  101?1  .06?47  .03?51
  .02198  .01520  .010.59  .00699  .00463  .00300  ,00239  :001119  .00116  .00091
  ,00069  .00040  .00030  .000??  .00014  .00010  ,00008  .00007  ,0000:,  ,00003
  .00002  ,00001  .00001  .00000  .00000  .00000  .00000"  .00000  .00000  .00000"

@BK2
```